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THE OBSERVER: AN INSTRUMENT OF PRECISION.

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The development of methods and technique in measurement is fundamental to the progress of any science. A science, like physics, in which these methods have been developed to a high degree is referred to as an *exact science.* The tools of an exact science are referred to as *instruments of precision.* Mathematical treatment of the data of scientific observation gives the scientist various measures of the degree of precision obtained. It must always be kept in mind, however, that the idea of "exact" or of "precision" is relative rather than absolute.

In practical life as well as in making scientific observations, we are constantly making use of instruments of precision. I look at my watch to see what time it is. Compared with the dollar watch I carried recently while this watch was being cleaned, my own watch is an instrument of precision. Compared with my watch, the chronometer in the window of the shop by which I set my watch last week is an instrument of precision, and yet this chronometer is corrected from time to time on the basis of reports telegraphed from the U. S. Naval Observatory at Washington, where other instruments of precision,—transits, micrometers, verniers, and the like, are used to determine the correct time. Thus we see that precision is a relative rather than an absolute matter. To take an example from Merriam's "Method of Least Squares", a certain angle was measured by the same observer with three different instruments, a theodolite, a sextant, and a transit. Four observations with the theodolite gave a result of 6°17′ 5″, with a probable error of 1.4″. Five observations with a sextant gave 6° 17′ 12″, with a probable error of 5.8″. Six observations with the

transit gave 6°17′0″ with a probable error of 23.3″. The true value of the angle is certainly in the neighborhood of 6°17′, since the results of all three instruments agree in this. But the limits between which the true result may be expected to lie vary with the three instruments. The true value as determined by the theodolite, the most accurate of the three, may, with a probability greater than one-half, be considered to lie between the values of 6°17′5″−1.4″ and 6°17′5″+1.4″, that is, between 6°17′3.6″ and 6°17′17.8″; and the transit, the least accurate of all, gives limiting values of 6°16′36.7″ and 6°17′23.3″. These are all instruments of precision and yet one has a higher degree of precision than another and in no case is the precision absolute.

Now when we consider the methods used in astronomy, physics, or any other of these so-called exact sciences we find that instruments of precision play an important part in them all, both in the observation of natural phenomena and in the development of experimental technique, as well as in the standardization or correction of other instruments. We realize further that in any of these methods the observer, the man who looks through the telescope or reads the thermometer, plays an important part. In fact, for the purposes of science, the observer himself is an instrument of precision. It is, therefore, interesting to the worker in any field of science to make a study of this useful and necessary instrument. The study of this human instrument is a major problem in the science of psychology.

The development of modern psychology has been characterized by a breaking away from the psychology of the past, which was based deductively upon a speculative philosophy, and by the foundation of a new experimental science, bringing to its service many of the instruments and methods of the older sciences, and inventing instruments and methods of its own. This modern movement is usually dated from the year 1878, when Wundt (1832-1916), then holding the chair of philosophy at Leipzig, founded at that university the first laboratory of experimental psychology. Wundt had begun his career as a professor of physiology at Heidelberg and brought to the new science of psychology the data and experimental procedure of this older science. In the nearly fifty years since that time, psychology has been developed as an experimental science which can no more stand by itself without dependence upon physiology than modern physiology can exist without chemistry.

Though the object of psychology continued to be defined as the study of the processes of consciousness, the principle came to be universally admitted that nothing happens in consciousness which is not conditioned by certain physiological processes. If one accepts the definition of psychology given by the more recent behavioristic school that "psychology is the science of the reaction of the individual to the stimuli to which his environment subjects him", this notion of the observer as an instrument of precision is still further emphasized.

Accepting this definition, we find that we are interested in an individual human being, not as a mind or soul made up of or possessing certain faculties such as cognition, will, and reason, but as an organism that reacts in a certain manner in a certain situation. We find that this reaction is determined by the arousal of certain physiological processes involving particularly the nervous system of the organism, and we have consequently seen the development of a psychology of the lower animals and of the human infant as well as an objective study of the human adult. It matters little for our purposes whether we consider only the reactions of the observer in a scientific experiment, or also make reference to his conscious states, and the terms "perceive" and "perception" will be used here without any necessary implication of one point of view or the other. In the sense that an instrument of precision is a *mechanism*, it may appear that the argument is in favor of a behavioristic interpretation, but the discussion is just as, or perhaps even more, pertinent to the methods of scientific observation if one makes his interpretations from the standpoint of psychophysical parallelism or interactionism.

That branch of psychology which seeks to determine the functional relation between the physical processes which we call stimuli and the reactions or mental processes of the organism is called *psychophysics*. For example, I ask someone to tell me which of the two weights is the heavier. If one of these weighs 100 grams and the other 120 grams he will very readily select the heavier, whereas, if one of them weighs 100 grams and the other 101 grams, he is very likely to tell me that the two are equal. Now the first weights act as stimuli giving rise to certain sensory reponses or perceptions of weight due to strain upon the muscles of his arm which are richly supplied with sensory nerve endings. Certain neural and brain processes are involved. The second case is similar, but in the first case the

weights are perceived as different and the judgment "heavier" is given, and in the other "equal", by which we imply that his perception of weight is not different from that aroused by the standard weight with which it is compared. We are interested in determining under what conditions his reactions to the weights are the same and under what conditions they are different. We seek further to formulate some mathematical statement which will generalize our findings, just as the astronmer or physicist derives his mathematical formulae.

We have here the concept of the sensitivity of the observer just as we speak of the sensitivity of a chemical balance which is used in comparing a given object with certain standard weights or masses. Closely connected with this idea is the concept of the *threshold*, a term introduced into psychology by Herbart in 1811. It is perfectly obvious that, in order to be perceived at all, a stimulus must have a certain intensity. Suppose we are looking at the stars on a clear moonless night. We can see stars up to the first, second, and third magnitude, and if our eyesight is keen, up to the sixth magnitude. But we know from using a telescope that there are thousands of stars too faint to be seen by the unaided eye. The intensity of light from one of of these is not great enough to arouse a sensory response. In other words, its intensity is below the threshold. The threshold may be defined, therefore, as that value of the stimulus which is just sufficient to produce a sensory response, less values producing no response.

It is clear that the value of this threshold for any given kind of stimulus may vary for different individuals and in the case of vision, for example, for the two eyes, and for different parts of the retina of the same eye, in the same individual. Its value will also vary with varying conditions of attention, expectation, practice, and fatigue. We see at once that the value of this absolute threshold of intensity is an index of the sensitivity of the observer. The lower the threshold, the greater his sensitivity; and the higher this threshold, the less his sensitivity.

To take another illustration from astronomy. Two observers, A and B, are gazing at a small constellation. A is a trained astronomer, while B is an amateur. A sees nine stars in the constellation, while B sees only seven. A makes a drawing of the stars in this constellation and shows B where the two stars which the latter does not see should appear, or he allows

him to observe them through a good field glass. He further shows B how to focus his eyes on a point a little to one side of the position where the stars are to be seen, as for dim light the center of vision is not the most sensitive portion of the retina. These changes in the method of observation, this practice, and attentive expectation act to lower B's threshold and he finds that he can now see nine stars in the constellation just as A does. His absolute threshold has been lowered and his sensitivity increased.

We sometimes speak of an upper threshold or limit of sensibility in contrast with that just described which is designated as the lower threshold. The upper threshold is that stimulus value beyond which there is no sensory response. Both are well illustrated in the case of tones produced by vibrating bodies or air columns. Some observers have claimed to hear as a tone the vibrations of a tuning fork vibrating sixteen times per second, but for most of us this lower limit is about thirty-two vibrations per second. On the other hand, as will be observed if we listen to a Galton whistle, we may shorten a vibrating air column, making the pitch higher and higher, until we pass the upper limit of sensitivity and no tone is perceived. This upper threshold for pitch is about 36,000 vibrations per second.

In light waves we find a similar phenomenon. If a beam of sunlight is diffracted by a prism or grating and thrown on a screen, we get a spectrum, but only a part of this will be visible to the human eye. We see violet, blue, green, yellow, orange, red; but it can be easily demonstrated in the physics laboratory that beyond the violet are the ultra-violet rays and beyond the red are the infra-red rays. The former are beyond the upper and the latter below the lower limit of sensitivity or wave length threshold and the latter below the lower limit of sensitivity or wave length threshold for the human retina.

The lower threshold values in animals are often quite different from those observed in the human species. Dogs have a remarkable sensitivity to olfactory stimuli. Romanes tells the story of a dog whose olfactory sensitivity was tested in the following manner. The dog's master walked nearly across a large field and turned abruptly to the right. He was closely followed by twenty-four men, each of whom tried to step exactly in the footsteps of the man in front of him. At the place where the owner of the dog turned to the right, the first

man following turned to the left, the second to the right and so alternately until twelve had followed to the right and the other twelve had gone to the left, each stepping in the other's tracks as before. A short time afterward, the dog was set on his master's trail, which he followed rapidly to the turning point. Here he ran past, but returned to "pick up the scent". This he did readily, following his master's trail without hesitation.

The problems of the psychophysicist are not limited to the determination of the limits of sensitivity—these upper and lower thresholds. Lying between these limits are series of stimuli all of which may give rise to parallel series of sensory responses varying in quality, intensity, and duration. The stimuli consist of some form of energy—kinetic energy, light, heat, etc.—which may be measured in terms of physical units. This light is 32 candle power, that is 16; this is a weight of 100 grams, that of 120, etc. Roughly speaking, the stimulus intensity series and the response intensity series are parallel. Two weights are heavier than one. A 32-candle-power light is brighter than one of 16 candle power. So true is this parallelism that our language is often confusing. We can not be certain which series is meant when some one says that "one sound is louder than another." The statement may refer to response intensity or to the intensity of the sound waves of the stimulus, or to both.

In spite of this rough parallelism, it can easily be shown that the response intensities may be indistinguishable, whereas the stimuli are clearly different, or that stimuli of equal intensities may be perceived as different. It is, therefore, the problem of psychophysics to study the relation which does exist between these two series.

This brings us to the concept of the *difference threshold.* In lifting two weights we may not be able to discriminate between 101 grams and 100 grams, the judgment "equal" being given. It is obvious that if we gradually add to the 101 gram weight we shall finally get a weight which will be judged "heavier" than our 100 gram weight. If such a weight is 103 grams, our difference threshold in the direction of increase is 3 grams. That is, a difference of 3 grams in stimulus intensity is just sufficient to produce discrimination. In a similar way by comparing weights of 99, 98, 97 grams, etc., with our original standard weight of 100 we come to a weight which is just perceptibly lighter than our standard. If this is 98 grams, our

difference threshold in the direction of decrease is 2 grams. A more sensitive subject might distinguish 102 and 99 grams from 100. His difference thresholds in this case would be therefore 2 grams in the direction of increase and 1 gram in the direction of decrease. The interval between these two difference thresholds is known as the *interval of uncertainity* since the person lifting the weights included in this interval can not judge better than by chance whether the comparison weight is heavier or lighter than the standard.

These measures of difference have been called "just perceptible differences." By taking account of these just perceptible differences in any given stimulus scale, either of quality, intensity, duration, or extent, we may arrange stimulus series which are paralleled by series of just distinguishable sensory responses or perceptions. The difference threshold may, therefore, be defined as the smallest different in two stimuli such that the two will be discriminated better than by chance. As it is a matter of relative stimulus value it may be stated in terms of the units of stimulus value or as a percentage. In this sense the difference threshold is comparable to the concept of probable error, the interval of uncertainty corresponding to the interval between the plusand the minus probable error.

The series of just distinguishable sensory responses are often very extensive. For example, in the series in the octave between A^{I} with 435 vibrations per second and A^{II} with 870, there are over 1200 tones which can be discriminated or are "just noticeably different", in the practiced ear of a musician.

It will make the concept of the lower threshold, or stimulus *limen* and that of the difference threshold, or difference *limen* clearer to mention a few analogies. The first is that of the tangent galvanometer first suggested by Delboeuf. (1831-1896).

The tangent galvanometer is an instrument for measuring an electric current by means of a magnetic needle suspended in the field of a coil of wire through which the current to be measured is passed. The angular deflection of the magnetic needle is observed and read from a graduated scale. It is found that the greater the current passed through the coil, the greater the total deflection of the needle from its original position. It is further observed that the amount of angular deflection due to a given increase in current is not, however, directly proportional to the increase in current, these increases producing less and less additional deflection the farther the

needle swings from the original position. Moreover, no current can be made strong enough to cause a deflection of 90″. It has been found that the current intensity is directly proportional to the tangent of the angle of deflection. The instrument is, therefore, called a tangent galvanometer.

If we observe the action of this instrument as our electric current is gradually increased we find an interesting phenomenon which is analogous to that observed in our stimulus-response series. First we note that the current has to be of a certain strength before the inertia of the needle and the torsive resistance of the suspension fiber are overcome and any deflection at all is noted. This corresponds to our lower limit of sensibility, our lower stimilus threshold. If a finer needle with a gossamer suspension fiber is used, this resistance may be reduced and our instrument rendered more sensitive, i. e. its stimulus threshold has been lowered.

The analogy can be carried still further, in that, when the needle is held at any given angle by a current of a certain strength, a further deflection will not take place, for the reasons mentioned above, until a certain amount of increase of current has been made which can overcome these resistances. This necessary increase is analogous to the difference threshold and may be greater or less according to the sensitivity of the instrument and to the position of the needle.

Another convenient analogy may be found in the chemical balance. Here scale pans are mounted at the two ends of a horizontal beam swinging freely in the vertical plane on an axis perpendicular to this plane of rotation. If these pans are in equilibrium a tiny bit of dust falling on one of them will not cause a tilting of the beam. But if dust should be allowed to accumulate on one of the pans the resistance due to inertia and friction would finally be overcome and this scale pan would drop and the apparent equilibrium would be destroyed. The mass of the dust necessary to effect this disturbance of equilibrium may be compared to the lower threshold of sensibility, the just perceptible stimulus already mentioned. If the balance were made more sensitive by reducing the friction, or the mass of the pans, or by increasing the length of the beam, this equilibrium would be disturbed by a smaller amount of dust, i. e., its stimulus threshold would be lowered.

If two equal masses are placed on these scale pans in their previous condition of equilibrium they will balance one another

and we have again a condition of equilibrium. To disturb this again it is necessary to add an appreciable amount to one of the pans. This is comparable to the difference threshold or just perceptible difference.

A third illustration may be found in observing the elasticity of a rubber band. It is necessary to exert a certain amount of force upon it before it will stretch at all. Again we have our lower threshold or limit of sensibility. After it has begun to stretch, relative changes in length will be proportional to the force exerted upon it. If held in a stretched position, however, an appreciable increase in the force exerted must be made before it will stretch further. Again we have our difference threshold. If force enough is applied, the limit of elasticity will be reached, the rubber band will break, and we have an analogy to our upper threshold or upper limit of sensitivity.

The human subject may be compared to such an instrument as the chemical balance. A weight must be of a certain intensity before it is perceived at all. A weight held in the other hand must have a "just noticeable difference" added to it before it is perceived as heavier. Here we have the stimulus threshold or limit of sensitivity and the threshold of difference.

These thresholds may be defined in specific units such as grams, candle-power, amperes, etc., or they may all be reduced to the absolute unit or energy, the erg. Thus Langley determined that the just perceptible light sensation under favorable conditions was stimulated by .0000003 erg. The just perceptible sound stimulus is represented by a figure considerably smaller.

Interest in these quantitative aspects of psychology, or in the science of psychophysics as it came to be called, dates from the researches of the German physiologist, Ernest Heinrich Weber (1795-1878), at the University of Leipzig, who in 1849 published his celebrated work "On the Sense of Touch and Organic Feelings." He experimented with lifted weights and found that he could just distinguish weights of 32 and 35 drachms. He found further that in order to make a weight just noticeably different from one of 32 ounces it was necessary to make a certain proportional rather than an absolute difference between the weights compared, i. e. 3 ounces instead of 3 drachms. Weber stated his conclusions as follows: "In the discrimination of objects that are compared the one with another, we do not perceive the difference between the objects but the ratio of this difference to the magnitude of the compared objects."

His work was followed by that of Gustav Theodor Fechner (1801–1887), who had at one time held the chair of physics and later that of philosophy at Leipzig. Fechner gave the name "psychophysics" to the new field of investigation, carried on many experiments in practically all the different sense fields, and wrote extensively on the subject's mathematical and philosophical aspects. He gave the name of Weber's Law to the psychophysical principle as stated by his predecessor.

Fechner sought to give a mathematical statement to the psychophysical law. The functional relationship between the sensory response series and the accompanying stimulus series he expressed by grading the former in an arithmetical progression and the latter in a geometrical progression. The mathematical relation between two such progressions or series may be expressed by saying that sucessive terms of one are respectively directly proportional to the logarithms of the successive terms of the other. Fechner's mathematical statement of the psychophysical law then becomes—

$$R \propto \log S$$

where R is the response or sensation and S the stimulus. Here we have a formula analogous to that for the magnetic deflection of the tangent galvanometer where

$$A \propto \tan \theta$$

when A equals the current strength and θ equals the total angle of deflection.

Fechner's law, as the logarithmic statement of the psychophysical principle has been called, may then be stated in one of two ways:

(1) *If stimuli are arranged in a geometrical series the sensations (responses) accompanying them will form an arithmetical series; or*

(2) *The sensation (response) is directly proportional to the logarithm of the stimulus.*

For Fechner, of course, the sensation aroused by a just noticeable stimulus was a sensation unit, in terms of which other supraliminal sensations and sensation differences as elements in consciousness could be measured.

An approximately exact illustration of this law is found in the magnitude of the visible stars. The classification of stars according to their brightness goes back to Hipparchus (125 B. C.) and Ptolemy, who divided the naked-eye stars arbitra-

rily into six "magnitudes", the first magnitude stars being some twenty of the very brightest and the sixth magnitude stars those just visible to the unaided eye. Now a first magnitude star is about one hundred times as bright as a sixth magnitude star. Stars may, therefore, be divided arbitrarily on the basis of photometric findings by the use of a light ratio of 2.51 ($\sqrt{100}=2.51$). That is, a star of the second magnitude is 2.51 times as bright as one of the third, one of the third 2.51 times as bright as one of the fourth, and so on. This method, first proposed by Pogson in 1850, has been generally adopted and most of the naked-eye stars have been measured photometrically and placed on this "absolute scale."

It would be gratifying if all stimulus series and response series parallel to them were found to conform to this simple functional relationship. When we test these series in different sensory fields for varying intensities, qualities, durations, etc., we find only a rough approximation of Fechner's law and that is usually limited to rather narrow ranges of these series. Weber's statement of the psychophysical principle is more nearly accurate because more general. We do not perceive or react to the difference between compared stimuli or objects, but the ratio of their difference to their magnitudes. Thus formulated we have a law which seems to be substantiated by the results of experimentation.

The data of extensive experimentation in this field both by the so called *gradation methods* and *error methods* (method of mean error, method of constant stimuli, etc.) are conveniently treated by the mathematics of probability and error in ways similar to the treatment of a series of data obtained from any scientific instrument of precision. The results show the sensitivity or degree of precision in any single observer as well as differences among different observers.

The statement of the principle of relativity as found in Weber's psychophysical law has not been confined to psychology. We find it in the principle of marginal utility in economics. As pointed out by Bernoulli (Daniel Bernoulli, 1700–1782), "we may regard the satisfaction which a person derives from his income as commencing when he has enough to support life, and afterwards as increasing by equal amounts with every equal percentage that is added to his income; and vice versa for loss of income." (A. Marshall, "Principles of Economics," 6th ed. p. 135.). Of course, the term "satisfac-

tion" is a psychological concept and the principle of Bernoulli and that of Weber are probably fundamentally the same. In other words, the "marginal utility" of any commodity to its possessor diminishes with every increase in the amount of this commodity which he already has.

Just as we notice the increase in light when a second electric light is turned on in a room but do not notice an additional light in the room already illuminated by a thousand lights, so ten dollars makes an appreciable increase in the monthly wages of a chauffeur but would not be noticed if added to the income of the millionaire whose car he drives. It is a "drop in the bucket" to use a folk-phrase expressing this principle, while "an inch on the end of a man's nose" is another folk-phrase to express a difference which is readily appreciable.

An example of this principle comparable to the psychophysical law is seen in the relation of rainfall to agricultural production. Before wheat can be grown at all a minimum amount of annual rainfall is necessary. This is the rainfall threshold, and we have a "just possible" wheat production. Even small increases in this rainfall yield rapid increases in the amount of wheat per acre which can be grown. But this rate of increase in production will fall off rapidly, and whereas an increase from 12 to 20 inches may double the crop, the increase from 40 to 48 will not do so. Finally a point is reached where further increase in rainfall will not increase the crop but may even be harmful and lessen production.

Scientific instruments frequently yield data which may show constant as well as variable errors. The constant error of a ship's chronometer is a certain regular rate of gain or loss per day. The instrument is set for Greenwich time and its time readings are compared from day to day with the true time as determined by some observatory. Its regular gain may be three seconds per day. This is a constant error. But continued observations show that it is not exactly three seconds: it is sometimes slightly more or slightly less than this. This difference is the variable error and may be due to one or many unavoidable causes. The navigator makes allowance for the constant error, but the variable error remains and must be taken into account as affecting the certainty of a given time observation. Considered as an instrument of precision the human being acting as an observer may show both constant and variable errors. This constant error when present in

observers is known as the "personal equation." The history of its discovery is interesting.

In the records of the Astronomical Observatory at Greenwich we find the following entry made by the British Astronomer Royal, Nevil Maskelyne, (1732–1811), who writes after holding that position for thirty years:

"I think it necessary to mention that my assistant, Mr. David Kinnebrook, who had observed the transits of stars and planets very well in agreement with me all the year 1794, and for the greater part of the present year, began from the beginning of August last to set them down half a second of time later than he should do according to my observations; and, in January of the succeeding year he increased his error to eight-tenths of a second. As he had unfortunately continued a considerable time in this error before I noticed it, and did not seem likely to get over it and return to a right method of observing, therefore, though with reluctance as he was a diligent and useful assistant to me in other respects, I parted with him.

"The error was discovered from the daily rate of the clock deduced from a star observed on one of two days by him and on the other by myself, coming out different to what it did from another star observed both days by the same person, either him or myself. . . . .

"I cannot persuade myself," he continues, "that my late assistant continued in the use of this excellent method (i. e., Bradley's eye and ear method) of observing, but rather suppose he fell into some irregular and confused method of his own, as I do not see how he could have otherwise committed such gross errors."

This record made by Maskelyne is the first account we have of any observation of a personal equation. Maskelyne considered that the discrepancies between his and his assistant's observations were due to some faulty method on his assistant's part and did not concern himself with investigating the matter further. The incident of Mr. Kinnebrook's dismissal was, however, mentioned in a history of the Greenwich observatory published twenty years later (1816) and here it attracted the attention of Bessel (Friedich Wilhelm Bessel, 1784–1846), the Konigsberg astronomer.

It was hard for Bessel to see how an assistant, who would have every reason for bringing his observations into agreement with those of his superior, should have so persistently shown this constant error. To test the matter for himself he compared his own results with those of other astronomers. In December, 1820, he observed ten stars on alternate nights with Dr. Walbeck, determining the rate of the clock as Maskelyne and his assistant had done. When they first compared their results

they found a difference not of 0.8 seconds, but of 1.1 seconds. Being trained astronomers, they took particular precautions on the following two days, but with very little difference in the result, for the discrepancy was nearly one second (average for eight days 1.04 seconds). So careful were they that Bessel wrote, "We ended the observations with the conviction that it would be impossible for either to observe differently, even by only a single tenth of a second." Still Bessel was not satisfied. Walbeck was less experienced in transit observations than he, and so similar comparisons were made either directly or indirectly with many of the best astronomers of Europe.

It became recognized, therefore, that there is in each observer a tendency to observe star transits in a characteristic way which may differ in time results from other observers equally well trained (the relative personal equation), and that these time results differ by a more or less constant amount from the true time measured (the absolute personal equation). What applies in observing star transits by the eye and ear method applies more or less generally in all cases where a person reacts in any way to a certain stimulus. This "constant error" is analogous to the error of the chronometer and in a similar way it may be determined within certain limits of variation and allowed for. We see, therefore, that in many ways the observer is an instrument of precision, having, as do other scientific instruments of precision, a certain degree of sensitivity, a certain interval of uncertainity, and certain constant and variable errors. We may infer also that the analogy of the galvanometer, the chemical balance, etc. is not certainly merely an analogy.

THE ALIMENTARY TRACT OF THE COMMON BUMBLEBEE.

MILLARD C. SWINGLE.

Introduction.

The insects as a class offer more opposition to man than does any other class of animals. Indeed, the order Hymenopetera is the only group which is truly beneficial to man. It includes the ants, all the bees, both polonizing and honey-making, and all the parasitic wasps which keep in check other insect pests. Since the group is one of man's greatest allies, a knowledge of them is of importance.

For the present study a representative type, the common bumblebee, *Bremus pennsylvanicus* was taken. This is a medium-sized species with a black head, a black band between the wings, and black underparts. The outer border of the tibia is concave. Only male specimens were used in this work.

All the specimens were fixed in Carl's Fixitive and were preserved in 70% alcohol. Following this, both gross dissection and micro dissection were carried out.

1. *Gross dissection.* This was done by completely removing the dorsal wall of the insect, including the head. The tract is held in place by muscles, trachea, and by the tissue composing the air sacs.

2. *Micro Dissection.* The entire alimentary tract, including the oesophagus and rectum, was removed and imbedded in paraffin. The section was pinned out on cardboard during clearing to insure all parts being on the same level. Sections were then cut eight microns in thickness and stained in Delafield's haematoxylin and eosin. Cross sections were also made of the parts desired.

Drawings of the muscular network of the canal were made from unstained mounts, so the nuclei were not drawn.

I wish to acknowledge my indebtedness to Dr. C. H. Kennedy, of the Ohio State University, for his assistance and criticisms in the preparation of this paper.

Gross Anatomy of the Tract.

I. Mouth-parts.
II. Fore Gut.
  1. Pharynx.
  2. Oesophagus.
  3. Honey Stomach.
  4. Proventriculus.
  5. Oesophageal Valve.
  6. Salivary Glands.
III. Mid Gut.
  1. Stomach.
IV. Hind Gut.
  1. Malpighian Tubes.
  2. Pyloric Valve.
  3. Intestine.
  4. Colon.
  5. Rectum.

THE MOUTH-PARTS.

The appendages of the head comprising the mouth-parts are practically external. The ventral part of the head has no chitinous floor of its own, but is closed by the bundle of mouth-parts fitting tightly against the opening. When extended, the mouth-parts are twice the length of the head, and are more or less heavily constructed.

They are composed of the following parts:

(1) The Hypopharynx, which is a long cylindrical tube covered with yellow spines. These are arranged in rows running spirally around the tube. The mouth is at the apex of the tube, on the ventral surface. (Fig. 2).

(2) The Labium, which is represented by the palpi only, extending out toward the end of the hypopharynx, is composed of three visible segments, the basal large, and the others very small.

(3) The Maxillæ are well represented by the long laciniæ which extend to the apex of the labial palpi.

(4) The Mandibles are short and extend only to the base of the hypopharynx.

All of these parts are capable of being folded into a cylindrical-shaped organ, which bends in the center and folds back under the head when not in use.

THE FORE GUT

The fore gut is ectodermal in origin, having been formed by the invagination of the fore part of the embryo. It is about a half inch in length, reaching from the mouth to the fore part of the mid gut. It is thin, membranous, and almost transparent its entire length, except for the proventriculus and oesophageal valve. (Fig. 1).

On leaving the proboscis, the tract bends foreward and upward into the fore part of the head. It passes along the

upper part of the head toward the back, where it suddenly bends and proceeds down through the two lobes of the brain, and then straight back through the thorax into the abdomen, where it ends at the junction of the first and second segments. It is cylindrical and relatively small for most of its length until it reaches the abdomen, where it is greatly dilated, forming the honey stomach.

The Pharynx resembles the oesophagus in general appearance, but is more dilated and irregular. It is several times the diameter of the oesophagus, at its anterior end, but narrows at its posterior border where it empties into the oesophagus. It is not clearly differentiated from the oesophagus anywhere along its course, except in size and possibly in having a thicker covering of muscles.

The Oesophagus is a long tube extending from pharynx to the honey stomach. Its diameter is constant throughout the entire length. Like the pharynx, it is practically transparent and has a waxy appearance.

The Honey Stomach is formed by the greatly dilated posterior end of the oesophagus. It is about six or eight times the diameter of the oesophagus. It also has the same structure and appearance as the pharynx and oesophagus. (Fig. 1).

The Histology of the Fore Gut is as follows:

(1) A cuticula of chitin on the inner surface.
(2) An epithelial layer of hypodermal cells.
(3) A basement membrane, secreted by the hypodermal cells.
(4) A band of longitudinal muscle fibers.
(5) A band of circular muscle fibers.

The three parts of the fore gut already mentioned are alike in structure, (See Figs. 3, 4 and 5, Plate I). The chitinous cuticle is the most prominent layer, and is about four times as thick as the others combined. It is not solid but is made up of a very thin and greatly convoluted sheet of chitin. Under this chitinous layer is an epithelium of very thin flat cells. These are more or less indistinct and in sections have the appearance of a number of nuclei connected by threads. The basement membrane is not apparent in this portion of the fore gut. The longitudinal musclar layer is also very poorly developed. It is represented by a few widely scattered bundles of tissue. The circular muscles are also poorly developed, being represented by a few scattered strands.

The Proventriculus, (Fig. 1, Plate II), is a fleshy tube-like continuation of the posterior part of the honey stomach. In junction with the oesophageal valve it forms a valve-like door for the fore part of the stomach. Its anterior end is closed by four triangular-shaped lobes of tissue, which lean inward when food is passing through. Their inner surface is covered with chitinous spines, which are long at the apex of the lobes and which become shorter as they extend downward along the wall of the proventriculus. They are directed posteriorly into the gut, and probably serve to prevent the food from being forced back out into the oesophagus. The entire inner surface is covered with chitin, which is in the form of a relatively smooth sheet. The epithelial layer is very well developed, being made up of a single layer of oblong cells packed closely together. The longitudinal muscles are very well defined, forming about one third the total thickness of the wall. They run continously from one end to the other. Around the whole is an enormously developed layer of circular muscles. The outer membrane is not apparent. This is the only part of the entire gut where circular muscles are even moderately well developed. It evidently acts as a force pump for the entire system.

The Oesophageal Valve defines the posterior limit of the fore gut, which is merely a continuation of the proventriculus into the mid gut. It is conical in shape and tapers toward its posterior end, where a thick tuft of convoluted chitin protrudes from the interior. The chitinous layer is thin and not so well developed at the anterior end, but becomes thicker and heavier at the apex. The epithelial cells are not clearly differentiated from the muscles, but are present nevertheless in a scattered layer. A basement membrane is not apparent but the layer of longitudinal muscles is very well defined. It is heavy at the base but gradually branches off and disappears at the apex. The circular muscles are very poorly differentiated, being represented by a few scattered bundles. Surrounding the whole is a fairly well defined sheathing membrane.

In the oesophagus the chitin layer is the most prominent, while the other layers are relatively unimportant. In the proventriculus, the circular muscles are most prominent with the longitudinal ones next. In the oesophageal valve the longitudinal muscles are by far the most important.

The Salivary Glands belong embryonically to the fore gut. There are three main glands, two of which are cephalic, and the other thoracic, (Fig. 8, Plate I). They are all paired, one gland lying on either side of the median line. The supercerebral gland lies against the dorsal wall of the head, and is the smallest of the three. A duct leads downward and forward, and enters the pharynx in the fore part of the head. The post-cerebral glands lie back of the brain in the posterior part of the head. The frontal gland is merely the fore part of the post-cerebral gland. A duct leads from them inward and enters a main duct in the center of the head, which empties into the hypopharynx. The thoracic glands are large, and lie about the oesophagus, extending about half way back through the thorax. A duct leads from them forward and empties into the duct from the post-cerebral glands. All of the glands are well developed and occupy a large part of their respective body cavities.

The fore gut appears to be a conductor only. Other than the salivary glands, there appear to be no cells for secretion in this gut. Food is merely carried from the mouth to the stomach by this gut, and with the exception of the salivary fluid, is not affected by it.

THE MID GUT.

The stomach comprises about one-fourth of the entire length of the alimentary canal. (Fig. 1, Plate I and Figs. 1 to 5, Plate II). In diameter it is about four times the size of either the fore or hind guts. It is entodermal in origin, being formed by a proliferation of rings of tissue from the free ends of the embryonic stomodeum and proctodeum. Its most conspicuous layer is that of the digestive epithelium. The cells are arranged in circular folds, there being approximately one hundred and forty folds from the oesophageal valve to the pyloric valve. The epithelium is somewhat columnar, but not strikingly so. The cells are rounded and present a diagrammatic regularity as they fold up and down, forming in longitudinal sections papillæ-like projections into the gut. This type of gut has been formed from a gut having a straight, flat epithelium. Pressure applied to the ends would force the epithelium to lap back and forth accordian-like, into folds extending circularly about the stomach.

Outside this layer of cells is a fairly well defined basement membrane, which is in contact with each cell in the fold. It therefore undulates in keeping with the epithelial layer.

Between the folds and at their base are scattered bundles of muscle fibres. These are circular muscles, and have been squeezed down between the walls of cells by the folding action of the gut.

On the outside is a thin layer of longitudinal muscles composed of bundles of longitudinal muscles connected by strands of lateral fibres, the whole forming a lattice-like network. Due to the scarcity of these strands, the external wall of the stomach appears corrugated. This layer may not be functional as a muscular layer, but rather as a covering. There is no apparent sheath-like layer beyond this. (Fig. 7, Plate I).

The area about the oesophageal valve is smaller in diameter than the rest of the gut, probably because of the fact that food rarely finds its way into this cavity, being emptied farther out into the gut at the end of the valve. The cells in this region are small and are of a dense type of protoplasm. The nuclei evidently are of a weaker structure, since they appear coarsely granular when stained. The cells appear to be non-functional as far as secretion is concerned. (Figs. 2 and 4, Plate II).

The portion of the stomach behind the opening of the valve presents an entirely different view. In this portion all of the cells, and especially those at the ends of the folds, are quite large. The nuclei are apparently very dense, for they stain evenly and very darkly It is not an uncommon thing to find cells here which are six or eight times the size of those about the oesophageal valve. Evidently this is the source of secretion in the gut. The secretion is holocrene in this type of gut. The cell forms the digestive enzyme within itself until a certain quantity is collected and then the cell bursts open, liberating the enzyme into the gut. The old tissue is detached and the newer cells behind it move forward and take its place. At the base of the fold is a group of small cells called a nidus. From this nucleus of cells new cells are formed which move out and take the place of the cells which have completed secretion. In this way there is a constant change of cells as secretion progresses. (Figs. 2 and 5, Plate II).

At the anterior end of the mid gut is a circular ring of cells which surround the base of the oesophageal valve and which secrete a thin membrane extending back into the gut. This is called the peritrophic membrane, and extends the entire length of the mid gut. At the apex of the valve there are several elongate folds of the stomach wall, which extend into the gut

almost to the valve. At this point the peritrophic membrane becomes thickened, but whether these folds have anything to do with secretion is not clear. The membrane is secreted only at the anterior end of the gut and is carried along to the other end by continued secretion.

THE HIND GUT.

The hind gut comprises about one-half the length of the alimentary tract. It is small in diameter and rather muscular for most of its course, but becomes translucent and thin at the colon and rectum. There are five main parts to the hind gut. (Fig. 1, Plate I, Figs. 1 to 5, Plate III).

The Malpighian Tubes. At the junction of the mid gut with the hind gut, is a series of small tubes branching off in all directions, called the Malpighian tubes. There are approximately one hundred and twenty-five to one hundred and fifty tubes in all. They are arranged in three parallel, circular rows about the gut, and are rather small in diameter. They weave in and out among the folds of the gut and serve to hold it in a compact mass in the center of the abdomen. They are probably urinary in function, emptying their contents into the hind gut. (Figs. 1, 4 and 5, Plate III).

Within each tube is a small canal. Next is a layer of cells forming an epithelium, which is relatively thick and forms the true body of the tube. The cells are somewhat flat, being about twice as broad as deep. Surrounding the whole is a thin membrane of connective tissue.

The Pyloric Valve is a ring of elongated cells extending down into the hind gut at its anterior end, just posterior to the Malpighian tubes. The epithelial layer of the gut has merely bulged out into the cavity, and the cells have become elongate.

The Histology of the Hind Gut is as follows:

(1) A cuticula of chitin on the inner surface.
(2) An epithelial layer of hypodermal cells.
(3) A basement membrane.
(4) A layer of circular muscles.
(5) A thin layer of longitudinal muscles.
(6) A layer of circular muscles.

The gut as a whole is ectodermal in origin, being formed by an invagination at the posterior end of the embryo.

The Five Parts of The Gut are as follows:

The Malpighian Tubes. These are tubes formed by the epithelium and basement membrane. They do not possess the other layers.

The Pyloric Valve. The general characteristics of this valve have been described above. Its histology is identical with that of the intestine, except that the epithelial cells are two or three times as long as those in the intestine.

The Intestine. The chitinous layer is thin and relatively smooth. It lies compactly against the tips of the cells and is not folded in any way. The epithelium is of the columnal type, with nuclei at the basal ends of the cells. The cells are rounded at each end and are about three times as long as broad. There is no very definite basement membrane. The three layers of muscles are not easily differentiated. The circular muscles are well developed, but the longitudinal muscles appear only as short strands connecting each circular bundle with the next. The inner and outer layers of circular muscles are well defined. They fit so closely together that they appear as one layer. This is due to the fact that the strands of the outer layer have fallen down between those of the inner. The two layers form a lattice-like network, with the main strands running circularly about the gut. At intervals between these circular bundles, there will appear a longitudinal bundle of muscles. There is no apparent membrane around the whole. (Fig. 6, Plate I).

There are five longitudinal folds of the epithelium extending into the intestinal cavity. These extend from the Pyloric valve to the rectum. They are produced by convolutions of the epithelial layer. (Fig. 2, Plate III).

The Colon. This is a large sac-like structure at the posterior end of the intestine, and into which it empties. It is thin, translucent, and waxy in appearance. In diameter it is four or five times the size of the intestine. The chitinous lining is greatly wrinkled and convoluted, while the epithelium and muscle layers are thin and serve only as a covering. It is similar in structure to the oesophagus and honey stomach. The muscular layers are very thin and indistinct, but the longitudinal layer seems to be the most prominent. The natural position of the colon is against the dorsal surface of the body wall.

The Rectum. The colon leads back posteriorly under a dorsal anal sclerite, where it becomes very narrow and enters the rectum. The rectum broadens out and has its entire dorsal surface attached to the sclerite above it. It is held in place also by a thin chitinous plate which entirely covers it below and is attached on either side to the sclerite above. The anal opening is merely an opening in the articular membrane at the end of this dorsal sclerite, beyond the rectum. The rectum itself is not constricted at its opening but opens with its entire diameter.

The rectum is more chitinous than any other part of the gut. Its epithelial layer and muscles form only a thin covering. No rectal glands were found. Perhaps they do not occur in the male bee, though they are so very conspicuous in other Hymenoptera.

Summary.

The alimentary tract as a whole is about twice as long as the body of the insect. The oesophagus is straight and leads back to the stomach in a direct line. The stomach and intestine are coiled upon themselves and are bound together by the mass of malpighian tubes. The fore gut is thin and practically transparent, except for the proventriculus and oesophageal valve. The mid gut is thick and corrugated, and is composed mostly of epithelial tissue. The hind gut is small and opaque except for the colon and rectum, which are somewhat transparent.

The entire system is rather simple and unspecialized. In each part of the canal there is but one prominent layer, which seems to have been evolved toward carrying on the entire function of that specific part of the gut. The other layers are often more or less discontinuous and vestigeal.

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EXPLANATION OF PLATES.

Plate I.

Fig. 1. A dorsal view of the alimentary tract. Oe.—Oesophagus; H. S.—Honey stomach; S.—Stomach; Int.—Intestine; Rec.—Colon and rectum.

Fig. 2. The mouth-parts (Mandibles not shown). Hyp.—Hypopharynx; La.—Lacinia; La. P.—Labial Palp.

Fig. 3. Cross section of the oesophagus.

Fig. 4. Cross section of the honey stomach. C.—Chitin.

Fig. 5. Section of wall of sesophagus. C.—Chitin; Ep.—Epithelial cells; C. M.—Circular muscles.

Fig. 6. Muscular network around Intestine. C. M.—Circular muscle; Int.—Intestine.

Fig. 7. Muscular network of stomach. L. M.—Longitudinal muscle.

Fig. 8. The salivary glands. Hyp.—Hypopharynx; S. D.—Salivary duct; Ph.—Pharynx; F. Gl.—Frontal or post-cerebral glands; Pc. Gl.—Post-cerebral Glands; T. G.—Thoracic Glands; Sc. Gl.—Super-cerebral glands; Oe.—Oesophagus.

Plate II.

Fig. 1. Longitudinal section of the proventriculus. L. M.—Longitudinal muscles; Sp.—Spine; Pvts.—Inner canal of proventriculus; Hy. Ep.—Hypodermal epithelium; C.—Chitin; Ho. St.—Honey stomach; M. G.—Mid gut; Es. V.—Oesophageal valve.

Fig. 2. Longitudinal section of oesophageal valve. Pvts.—Proventriculus; Oe. V.—Oesophageal valve; St.—Stomach.

Fig. 3. Diagramatic sketch of one-half of stomach, showing arrangement of the inner folds.

Fig. 4. A section of two of the folds in the fore part of the stomach lying about the oesophageal valve. C. M.—Circular muscle; C. Mar.—Ciliated margin of cells.

Fig. 5. A section of two of the folds of the stomach beyond the oesophageal valve. N.—Nidus; C. M.—Circular muscles; C. Mar.—Ciliated margin of cells.

Plate III.

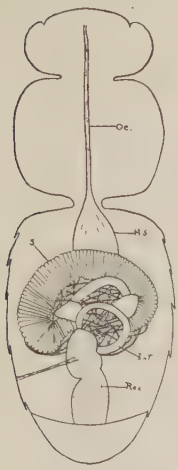
Fig. 1. Longitudinal section of pyloric valve. Int.—Intestine; Ep.—Epithelium; C.—Chitin; C. M.—Circular muscles; V.—Valve proper; M. T.—Malpighian tubes; St.—Stomach.

Fig. 2. Cross section of intestine. Ep.—Epithelium; L. M.—Longitudinal muscles; C. M.—Circular muscle.

Fig. 3. Longitudinal section of junction of intestine and colon. Int.—Intestine; Ep.—Epithelium; Rec.—Colon or rectum.

Fig. 4. Cross section of Malpighian tube.

Fig. 5. Longitudinal section of Malpighian tube.



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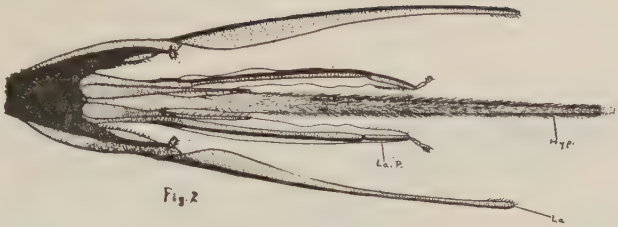

Fig. 2

Fig. 5

Fig. 3

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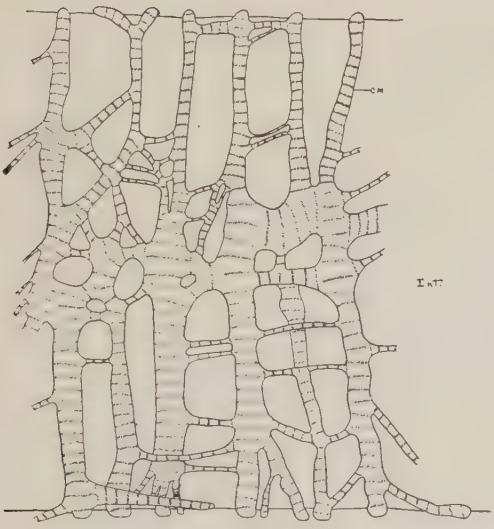

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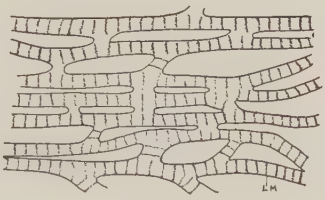

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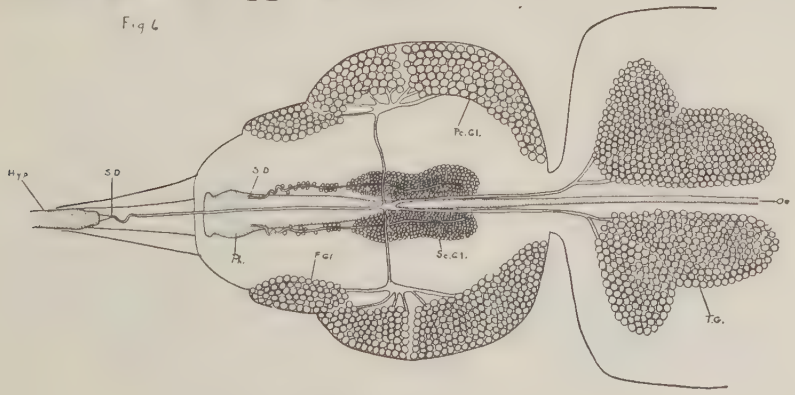

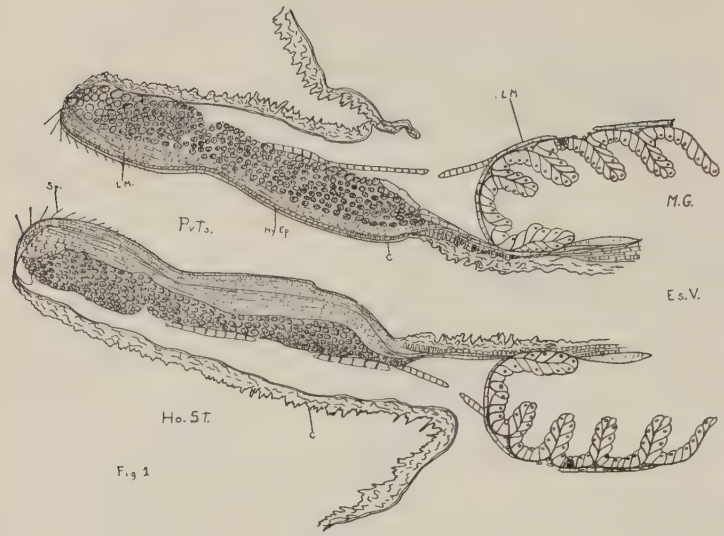

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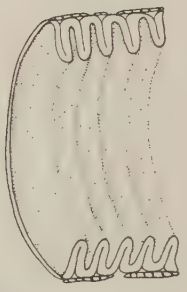

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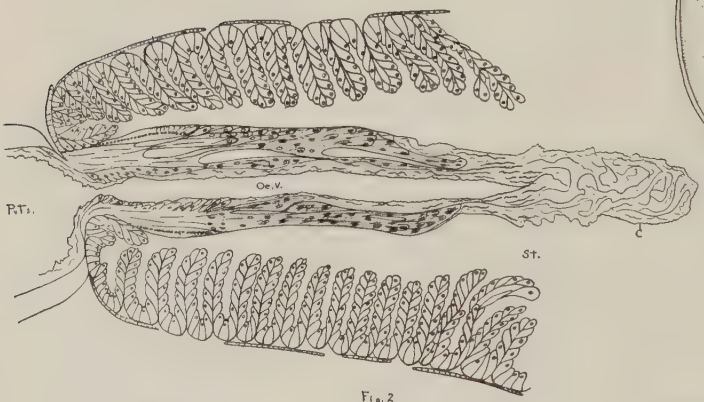

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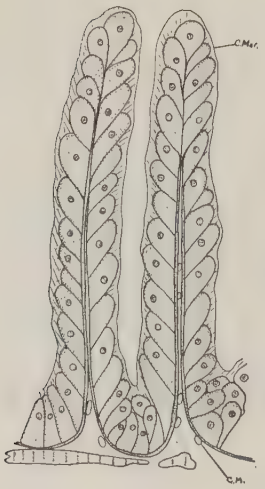

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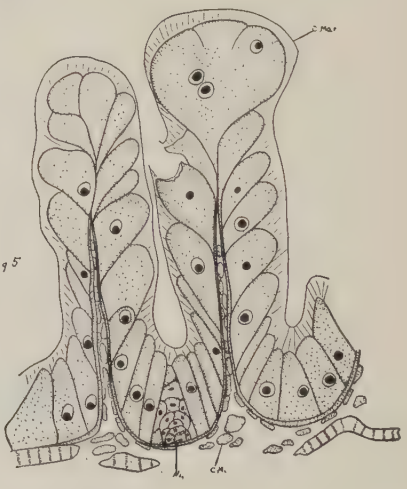

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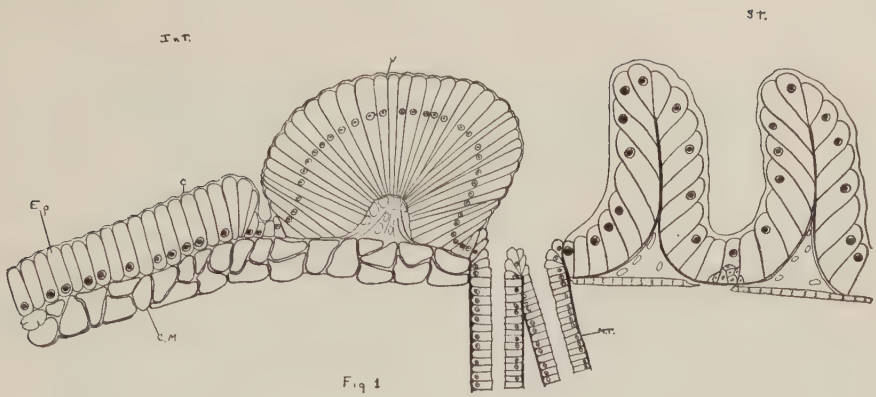

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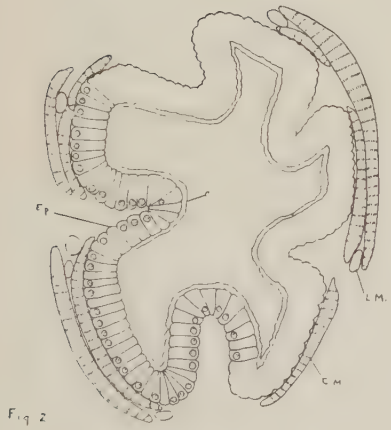

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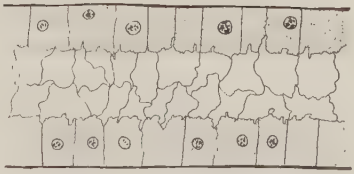

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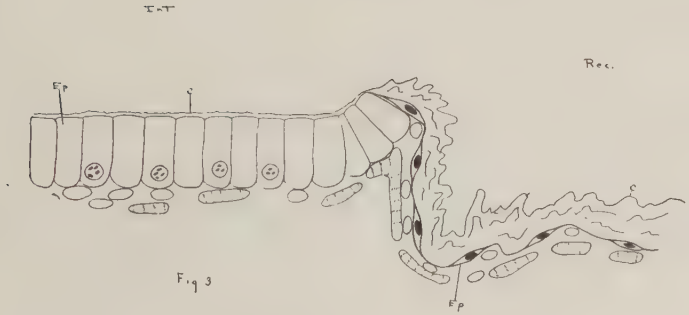

Fig 3

FUSARIUM MONILIFORME IN RELATION TO DISEASES OF CORN.

D. P. LIMBER.

Introduction.

The fungus, *Fusarium moniliforme* Shel. has been reported by several workers (15) (20) to be the cause of ear, stalk, and root rots of corn. The rotting of the corn plant causes very serious losses to the crop. Other organisms parasitic on corn are known to cause the rotting of ears, stalks, and roots of corn, notably, *Diplodia zeae* (Schw.) Lev. (2) *Gibberella saubinetii* (Mont.) Sacc. (7), *Helminthosporium sp.* (18), and certain bacteria (14). Hoffer and Carr (6) have shown that effects very similar to stalk and root rots are produced by excessive accumlation of iron and aluminum in the roots and stalks of corn.

The consideration of *F. moniliforme*, specifically, as one of the major causes of stalk rot and seedling blight began with Valleau's work (20) in 1920. Since that time some workers have advanced evidence supporting Valleau's findings, others have secured contrary results.

The work reported in this paper was undertaken to ascertain if *F. moniliforme* is capable of causing a serious seedling blight of corn; if *F. moniliforme* causes broken and leaning stalks in the field; to what extent it causes molding of ears; and in what way infection reaches the kernels. Incidentally, the problem of seed treatment was taken up in order to secure disease-free seed for inoculation purposes.

A review of literature follows which shows the present status of these problems.

Review of Literature.

The fungus known as *F. moniliforme* Shel. was described by Sheldon (15) in Nebraska in 1904. He isolated it from ears of corn showing a pink mold, and described it as follows:

"Sporodochium, subeffuse, salmon-pink; sporophores, simple or branched, usually opposite; microconidia, continuous, oblong-

ovoid, moniliform, 6–10u long; macroconidia, falcate, acute, for the most part three-septate, 25–40μ long".

Sherbakoff (16) states that "among the *Fusaria* answering Sheldon's description of *Moniliforme* are several that differ from each other in important characters and are thus different organisms." On these grounds he set up the section *Moniliform* as follows: "Macroconidia type intermediate between *Roseum* and *Elegans*, thin walls mostly three-septate; microconidia also in chains, chlamydospores none, color of substratum from none to violet."

Manns and Adams (11) identified *F. moniliforme* with *Oospora verticilloides* Sacc. reported from Northern Italy in 1881.

Wineland (21) at Wisconsin reported that perfect perithecia were produced when two distinct strains of *F. moniliforme* were plated together. The perithecia were born at the lines where the two strains came in contact. Ascospores from these perithecia on germination gave pure cultures of *F. moniliforme*. The cultures which produced the perithecia were somewhat different morphologically. The perithecia resembled those of *G. saubinettii*.

Stover (18) at Wisconsin studied the effect of temperature on the growth of *F. moniliforme* in culture. After five days visible growth had occurred at a temperature of 12° C., was considerably greater on plates up to 18° C., then increased more gradually to an optimum from 26° C. to 33° C., after which it decreased markedly at each higher temperature. There was little growth at 37° C. Henry (5) gave its temperature range as follows: "slightly at 5°–7° C., optimum at 30° C., and slightly at 36°–36.5° C. He also reports isolating *F. moniliforme* from the soil.

It is probable that many investigators have worked with *Fusarium moniliforme* in connection with studies of seedling blight of corn. There are many papers on this subject which do not name all the organisms studied. Burrill and Barrett (2), Holbert and Hoffer (8), and Pammel, King, and Seal (13) mention a *Fusarium* in this connection.

Valleau (20) in 1920 was the first to assign to *F. moniliforme* any large part in the production of root and stalk rots. He found that it was almost universally present in Kentucky seed corn. He also secured corn from other states and found infection equally high. On the basis of his work he believed

that *F. moniliforme* was an active parasite, more virulent than *G. saubinettii*, that it was capable of causing root and stalk rots in the field, but that it did not injure germination unless infection were very severe. Manns and Adams (10) in Delaware report that *F. monilforme* is very common in seed corn. Branstetter (1) in Missouri found *F. moniliforme* was present in 68.8% of the ears he tested. He also reported a correlation between badly diseased corn, as shown by the germinator test, and low yields. Melchers and Johnson (12) in Kansas found nearly 95% of the seed corn was infected, but could find no correlation between the results of the germination test and stalk and root rot injury in the field.

Sherbakoff (17) reports that seed effectively treated for *F. monilforme* gave no better yield than untreated seed. He suggests that either it is not pathogenic or that it is always present in the soil. Valleau (20) reported that he could find no effective treatment. Manns and Adams (11) state that the internal nature of the infection makes seed treatment ineffectual. Branstetter (1) states that seed corn can be effectively treated by soaking it in mercuric chloride (Hg Cl 1) 1:1000 for one hour.

The effect of soil temperature on the blighting of corn seedlings inoculated with *F. moniliforme* was investigated by Stover (18). He found that *F. moniliforme* attacked corn through a range of soil temperature from 10° to 36° C. However, at the lower temperatures, infection was rare and was shown only by small brownish-yellow lesions which did not represent a serious injury. At 28° to 36° C. seedlings showed considerable injury and *F. moniliforme* was frequently isolated from the lesions. It was thought that high temperature with consequent drying of the surface soil was at least in part responsible.

F. monilforme has been reported from hosts other than corn. Hartley, Merrill, and Rhoads (4) as early as 1918 found that *F. moniliforme* caused normal damping off of conifer seedlings, but was not responsible for germination injuries except when heavy inoculation was practiced. They concluded that it was less important in damping off of conifer seedlings than *Corticium* and *Pythium*. Henry (5) inoculated *F. moniliforme* into wheat, sweet corn, rye, and oats, all of which it attacked.

Experimental Work

The writer's work with *F. moniliforme* Shel. was undertaken during the summer of 1923 at Ohio State University. A small plot of corn in the Botany Department garden was used for field inoculations. The seedling inoculations and soil temperature experiments were carried on in the department greenhouse and laboratory.

Many strains of *F. moniliforme* were used during the progress of this work. Three strains were secured from Mr. R. A. Dobbins, a graduate student in the Department of Botany. Two were isolated from blighted corn seedlings sent in from Morrow County in June 1923. The others were isolated from kernels of corn. In all thirteen strains were secured. Single spore isolations were made from five of these. All of the strains produced macroconidia in chains. The microconidia were produced abundantly in old cultures which had been kept moist. Three and four septate macroconidia were the most common. Five septate macroconidia were frequent. These latter often measured 50–60μ in length.

From a study of the morphology and physiological reactions of these strains in culture it became apparent that they could be separated into at least two distinct groups. The mycelium of the group most closely answering Sheldon's description had a pink tint, was loosely matted, and grew freely into the air. The substratum was deeply colored, ranging from greenish blue or purple on potato dextrose agar with 2% sugar to a deep plum purple on potato dextrose agar with 5% sugar. The mycelium of the other group was pure white and formed a low, dense mat. The substratum was never more deeply colored than salmon. These differences are in agreement with Sherbakoff's statement that the fusaria producing spores in chains include several distinct organisms.

Field Inoculations.

During the first week in August twenty-five stalks were inoculated just before the tasseling stage to ascertain whether *F. moniliforme* causes stalk rots. A small hole was made in the stalk by puncturing it with a cork borer one-eighth inch in diameter. A fragment of the medium upon which *F. moniliforme* was growing was inserted into the puncture, and the opening was closed with absorbent cotton. The cork borer

and needles used were sterilized in the flame of an alcohol lamp before each operation. Control stalks were prepared in the same way except that no inoculum was placed in the punctures. Inoculations were made at various heights from the ground. The media used were potato dextrose agar and steamed rice.

Two inoculated stalks and two checks were cut and examined after three weeks. Others were cut from time to time until the third week in October. In some stalks it was found that the cork borer had penetrated only the sheaths, the stem not having developed far enough to be encountered. The elongation of the internodes had then pushed the sheaths upward and separated them. The mature plant showed the puncture made by the cork borer in several successive sheaths. These punctures were surrounded by a purplish-black ring of discolored tissue. This is shown in Plate I, a. The check plants did not show this discoloration. In other stalks the cork borer penetrated the internodes. Externally the symptoms were the same as found on the sheaths. When the stalks were split through the wound longitudinally, wide streaks of the pith and vascular bundles were found to be black or brown. These streaks were usually very conspicuous within the internode punctured. This is shown in Plate I, b. In the internodes above and below it they appeared less prominently until in the third or fourth nodes it was confined to the vascular bundles. In one stalk these discolored strands were traced to the sixth node above and to the third node below the inoculation point.

Tissue from the brown strands was taken from six stalks and plated on potato dextrose and corn meal agar. *F. moniliforme* grew out from the tissue in all instances, in one case from tissue taken from a point twenty inches above the puncture. In no case did this discoloration extend into the shank of an ear.

The controls showed a light browning around the wound never extending more than two inches from the injury. No *F. moniliforme* appeared when browned tissue from this source was plated. Several plates showed no fungus growth of any kind. The color of the tissue was probably caused by the death of the cells due to the injury and consequent drying.

Inoculations of leaf sheaths and of stalks made by puncturing these parts with a sterile needle and applying a loop of a spore suspension produced only the local symptoms noted above, purplish-black discolorations confined to the area inoculated.

Five stalks were inoculated by pouring several c.c. of a spore suspension between the sheath and the stalk. No infection could be found when these were examined.

Inoculation on Young Silks.

Valleau (20) suggests that in the ear rot produced by *F. moniliforme* the silks are the path of invasion. To secure data on this point eighty ears were covered with glassine paper bags before the silks appeared. Natural infection of the silks was thus presumably prevented. When the silks were well exposed within the bags, the bags were removed, the silk was pollinated by hand and then sprayed with a suspension of spores of *F. moniliforme*. The bags were then replaced. A large number of control ears were prepared. A severe storm of wind and rain tore or blew off almost all the bags. The purpose of the experiment was defeated by the exposure of the control ears to infection. However, the ears were again covered with a stronger type of bag.

About forty ears each of the inoculated lot and the controls were tested by the modified rag doll method after harvesting. All showed infection. External molding occurred on three or four ear tips to which the corn ear worm had gained access. No other molding was found. This is interesting in view of the heavy inoculation practiced.

Direct Inoculation of Kernels.

The husks of eleven ears were slit with a knife and spores of *F. moniliforme* were sprayed on the kernels. This was done when the kernels were just past the dough stage. In four cases the kernels were wounded, in two they were un-injured by the knife, and in the other cases no attention was paid to this point. Checks sprayed with sterile water were made. In both checks and inoculated ears the slits in the husks were made tangent to the ear in such a manner that the husks would cover the sprayed kernels completely. In ten ears a mold developed, but it was usually confined to from three to six kernels, sometimes scattered. One ear was completely involved. On October fourth nineteen more ears and several checks were prepared in the same way. The corn was nearly ripe and fairly dry. Of these ears only one developed mold.

Inoculation in Cobs of Young Ears.

Seventeen ears were inoculated by puncturing with a cork borer through the husks into the cob of the green ear, then inserting into the cavity a sweet clover stalk or apple twig on which the fungus was growing. These ears were affected much like the preceding. Localized areas where the cavity was near the surface of the cob would show moldy, shrunken kernels. The checks showed no mold. The appearance of this infection is shown in Plate I, c.

Discussion of Results of Field Inoculations.

The results of inoculating the young stalk just before tasseling show that *F. moniliforme* is able to grow parasitically in the stalk tissues and to produce the discolorations characteristic of stalk rot. The absence of broken and leaning stalks seems to indicate that the injury is of a mild character. The slight infection secured in the needle puncture inoculations and the failure of the spore suspension to produce infection when poured under the sheath strengthen this view. As it is possible that other environmental conditions might have changed the results, it would be desirable to repeat these experiments and to make the stalk inoculations earlier in the life of the plant.

F. moniliforme is capable of causing molding of ears but probably requires very moist conditions to cause general molding. It does not attack the husks as freely as *Diplodia zeae* (Schw.) Lev. and *Gibberella saubinetii* (Mont.) Sacc.

Seedling Inoculation.

Inoculation of Seeds at Planting.

Thirty ears were tested for internal infection of *F. moniliforme* by plating pieces of surface sterilized kernels in agar. By this method *F. moniliforme* infected ears and ears apparently free from any fungus were selected. Seed of both kinds was surface sterilized in mercuric chloride ($HgCl_2$) 1:1000 and planted in clean, white sand. Twenty-two apparently disease-free, twenty-three diseased, and twenty-four apparently disease-free inoculated seeds were planted. Each seed was placed in a separate pot and the pots were set closely together in a shallow box. The interspaces were filled with sand to help hold the

moisture. The pots used were made of paper of the type used in making rag doll germinator rolls. Planting each seed in a separate pot prevented the fungi from passing from plant to plant and made it easy to secure the entire root system for examination. The plants were watered with a dilute nutrient solution. They remained thrifty and of good color throughout the experiment.

All of the plants were allowed to grow for four weeks. The soil temperatures ranged between 15.5° and 22° C. At the end of that time the infected and inoculated lots were slightly larger than the apparently disease-free. The difference was thought to be due to temperature as the latter showed a soil temperature 1° to 2° C. lower because of its location farther from the steam pipes. There were nine weak plants from the

TABLE I. COMPARISON OF APPARENTLY DISEASE-FREE, INOCULATED, AND NATURALLY INFECTED SEED GROWN IN SAND FOR ROOT ROT INJURY.

Seed	No. Plants	No. Plants Infected	No. Plants Clean	Percent Clean
Apparently disease-free	22	14	8	36
Inoculated	24	19	5	24.6
Infected*	23	21	2	8.6

diseased seed, four from the inoculated seed, and three from the apparently disease-free seed. The percentage of plants found to have clean roots was 8.6%, 24.6%, and 36% for the infected, inoculated, and apparently disease-free, respectively. Few of the injuries were of an extensive nature. Tissue from the rotted roots and mesocotyls gave *F. moniliforme*, *Gibberella saubinetii*, and other fungi. As the seed used in apparently disease-free and inoculated lots was from the same ears, some infection due to the inoculation is indicated.

This experiment was repeated until in all over four hundred seedlings had been grown. In some of the later lots individual potting was omitted.

This work demonstrated that with the seed used freedom from infection occurred only in individual kernels. No ears were found which were entirely free from *F. moniliforme*. The

*It should be noted that one of the infected ears was of a poor type and not suitable for seed.

percentage of infection was found to vary. Inoculation of ears showing a low percentage of infection increased the amount of infection shown by seedlings grown from such seed. The infections secured under the conditions obtaining in this experiment did not affect the vigor of the plants or cause blighting. It would appear that under these conditions the progress of the infection does not keep pace with the growth of the root system.

Seed Treatment.

The experiments discussed above brought out forcibly the need for disease-free seed or some method of seed disinfection. As no ears had been found to be completely free of fungus infection, several experiments were undertaken in an attempt to find efficient method of seed disinfection.

Hot water treatments proved ineffective. Serious injury occurred at temperatures of 60° C. when maintained for over ten minutes. Seed treated below the point of injury was not disinfected.

Javel water, as used by Duggar and Davis (3) was also tried but did not give complete disinfection.

Mercuric chloride (Hg Cl_2) 1:1000 was also tested. It was found that seed killing began between two and one half and three hours. Some disinfection was obtained when seeds were soaked for one hour and forty-five minutes, but the results were not uniform. Disinfection was then attempted by soaking the seed for ten to fifteen minutes in mercuric chloride at a temperature of 50°–60° C. Several small lots of seed treated by this method and tested were found to be free of *F. moniliforme.* Other lots were then treated by the same method with contradictory results. Incomplete disinfection occurred in some cases; total failure resulted in other cases in which heavily infected seed, as determined by agar plating, was used. These results are perhaps explained when it is remembered that the amount of infection in the different kernels varies widely as is shown by plating and other tests. When infection is light and presumably carried in the more accessible parts of the pericarp, a high percentage of disease-free seeds can be secured by this method.

Soil Temperature Effects on Pathogenicity of F. Moniliforme.

The effects of soil temperature on the parasitism of *F. moniliforme* on corn seedlings were studied by the use of temperature tanks of the Wisconsin type. These tanks are described by Jones (9). These tanks are filled with water, and heated with electric space heaters placed in copper tubes which extend through the tanks near the bottom. The higher temperatures are regulated by electric thermostats. Temperatures below 20° C. are secured by running cold water through the tanks.

The cans were made equal in weight by the addition of pieces of crockery and then filled with equal weights of good soil. The moisture content of the soil was ascertained and corrected to about 24% of the dry weight of the soil. This percentage was maintained by weighing the cans once or twice daily and adding water as was necessary.

The experiment was divided into three parts. One hundred and twenty seeds known to be heavily infected with *F. moniliforme* were inoculated by placing them in a heavy spore suspension, and planted. One hundred and twenty seeds from ears known to be lightly infected were treated by heating in mercuric chloride to 55° C. for ten minutes, followed by thorough rinsing. One half of these disinfected seeds were then inoculated in the way just described, the remainder were planted as a control. By the use of disinfected seed for the control the amount of infection from fungi in the soil would be shown.

The temperatures used were 12°, 16°, 20°, 24°, 26°, 28°, and 32° C. At 32° C. the corn came up in about 2 days and 18 hours, at 28° in 3 days, at 24° in 4 days, at 20° in 5 days, at 16° in 7 days, and at 12° in 15 to 17 days. The disinfected seed germinated 100%, but came up a little more slowly. After the tenth day a tendency to tip burn, and a weakness of the stalks appeared in the inoculated cans at 32° and 28°C. As the experiment progressed, many plants at these temperatures fell over. The check plants were notably stronger and nearly normal in appearance to the end of the experiment. The results of this experiment which was closed after three weeks are presented in Table II.

At 32°C. the control plants were strong and erect, although one plant showed some wilting of the top. The roots or mesocotyls of five plants showed serious rotting; five showed slight

rotting, chiefly of the seminal roots. The old kernel still adhered to the mesocotyls. The disinfected, inoculated plants, of which there were ten, were down badly. The kernels had rotted free of the mesocotyls. Six plants showed serious rotting, while four were only slightly rotted. The twenty infected, inoculated plants were also down quite generally. Two plants were nearly dead and four others were stunted. Fourteen plants had badly rotted roots.

At 28°C. the condition of the plants was much the same as at 32°C. At 24°, 20°, and 16°C. the plants stood up well and appeared to be quite vigorous. The rotting of the roots was not of a serious character except in a few plants. At 12°C.

TABLE II. PERCENTAGES OF PLANTS SHOWING INFECTION WITH F. MONILIFORME AT DIFFERENT SOIL TEMPERATURES.

	No. Kernels	Percentage of Plants With Rots or Lesions on Roots or Mesocotyls					
		32°C.	28°C.	24°C.	20°C.	16°C.	12°C.
Control	20	80	45	40	10	0	30
Treated seed, inoculated	20	85	90	41.5	25	5	10
Naturally infected seed, inoculated	40	87.5	92.5	90	50	10	22.5

infection was confined to small lesions, but a serious killing of the tap-root tips occurred which was more common in the cans in which treated seed was used. The plants in the can which showed the most serious killing of the tap roots were from seed from which *F. moniliforme* could not be isolated when plated. These facts suggest that the killing referred to was chiefly a temperature effect, accentuated by some residual effect of the seed treatment.

This experiment was repeated. In the second series the same type of seed was used in all of the cans. It was seed known to be heavily infected with *F. moniliforme*. Two cans of soil for the 32° C. tank were autoclaved for one hour and thirty minutes at 15 pounds pressure. The treated control seed was planted in one of these and the treated-inoculated seed in the other. In this sterile soil 50% of the plants were killed within two weeks. *F. moniliforme* grew visibly on the plants at the surface of the soil. Of the plants in the unsterile

soil at the same temperature all were alive, although two plants showed some wilting. The seed treatment (hot mercuric chloride) was much less effective with this seed and the infection in the control lot was greater than in the first series. Otherwise the results of the two series checked quite closely. The combined results are given in Tables II and III.

Table II is based on a count of all rotted areas and lesions found on the mesocotyls and the seminal and tap roots. The percentages given do not indicate the seriousness of the injury, but the percentage of plants infected.

Table III is based on a count of the plants which showed rotting areas on the mesocotyls or roots, of an actively pro-

TABLE III. PERCENTAGE OF PLANTS SHOWING ACTIVELY PROGRESSING ROTTING AREAS CAUSED BY F. MONILIFORME AT DIFFERENT SOIL TEMPERATURES.

	No. Kernels	Percentage of Plants Showing Actively Progressing Areas on Roots or Mesocotyle					
		32°C.	28°C.	24°C.	20°C.	16°C.	12°C.
Control	20	45	15	0	0	0	0
Treated seed, inoculated	20	60	35	5	5	0	0
Naturally infected seed, inoculated	40	70	65	30	2.5	0	0

gressing nature. Lesions and very small infected areas were not considered.

These tables show that the rotting caused by *F. moniliforme* occurs chiefly at temperatures above 20°C. Serious injury was confined to the two higher temperatures, 28° and 32° C. Many plants on which rotting areas were found were not inferior in growth or vigor to the unrotted plants. This was particularly true of the plants grown at temperatures below 28° C. In the lots grown at temperatures of 28° and 32° C. plants which showed wilting and tip burn at two-and-one-half to three weeks of age frequently were observed to show improvement at the end of four weeks. When taken up for examination the mesocotyls of these plants were found to be completely rotted off. The recovery of the plants was to be attributed to the appearance of the permanent roots from the lower nodes.

The results reported in Table II agree very well with those secured by Stover (18). But owing to the fact that Stover could not reisolate *F. moniliforme* from the infected tissues in all cases, and that other fungi were almost always present in such tissue, he did not consider the pathogenicity of *F. moniliforme* to be satisfactorily established. In the experiments reported above *F. moniliforme* was reisolated from diseased tissue in nearly all cases when plated. From this evidence there seems to be little doubt that *F. moniliforme* can cause serious injury at temperatures above 28° C. when other conditions are favorable. It also would appear that *F. moniliforme* is more virulent in sterile soil. Whether this is constant and whether it is due to biologic, chemical, or physical factors remains to be determined.

It was strongly suggested that the death or survival of infected plants depends upon the speed of the fungus in destroying or cutting off the temporary root system before the permanent roots begin to function. Referring again to the work of Stover (18) and Henry (5) we find the optimum temperatures for growth of this fungus in culture are given as 26°–33°C. respectively.

In searching for statistics on soil temperatures of the corn belt states it was found that there are few available. Swezey (19) at Lincoln, Nebraska, recorded the soil temperature through a period of twelve years. His tables show that at Lincoln the maximum temperature of the soil at a depth of three inches, during May, exceeded 26° C. only three times in twelve years. The mean temperature lay between 15°–24° C. For June the maximum ranged from 23.3°–40.5° C. and the mean from 19.5°–31° C. These are day temperatures. The night temperatures are lower, often by as much as 5°–8° C. If these statistics are representative of the corn belt, it appears that only on occasional years would soil temperature favor serious corn seedling injury due to *F. moniliforme*.

Conclusions.

It is clearly shown that *F. moniliforme* may grow parasitically within the growing stalk, but no effects, shown by broken and leaning stalks, are produced when infection occurs as late as August. No data as to the effect of earlier inoculation was secured.

The inoculation of ears demonstrates that this organism may grow externally on the kernels when moisture conditions are favorable. The area infected externally is usually very limited. The resistance to external molding of the kernels is greater when they have passed the dough stage.

As the possible cause of a seedling blight of corn its relations are interesting. It is present in a high percentage of Ohio seed corn. It was also isolated from the soil. But that it is an organism producing serious injury to corn seedlings at the normal soil temperatures for May and early June could not be demonstrated. The characteristic lesions produced by *F. moniliforme* on the mesocotyls are small, oval, yellowish areas, with a darker spot in the center in old lesions. On the roots the lesions are usually darker. At temperatures of 24° C. small rotted areas may be produced on the mesocotyl, usually close to the seed. At temperatures above 28° C. serious injury may occur.

Soaking the seed in mercuric chloride for two hours at room temperature or for ten minutes at 55° C. will completely disinfect lightly infected seed. No seed treatment was found which would give perfectly clean seed when infection was heavy.

The hot mercuric chloride treatment of seed retards germination a little, but apparently causes no real injury.

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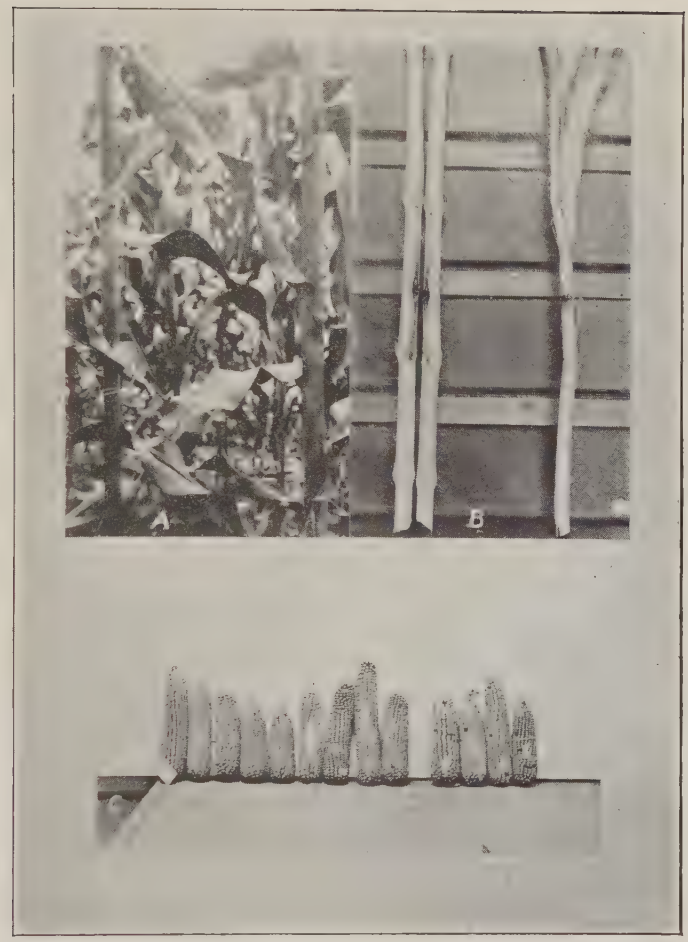

A. General appearance of plants inoculated in the young stalk. Left, inoculated plant. Right, control. Photo taken about two weeks after inoculation.

B. Stalks inoculated in the manner shown in "A" split for examination. Inoculated stalk at the left; check at the right.

C. The nine ears on the left were inoculated by spraying with a spore suspension through a slit in the husks; the four on the right by inserting *F. moniliforme* growing on an apple twig or sweet clover stem into a cavity made in the cob.

A. These plants show method of individual potting described under Seedling Inoculations. Tray at left contains control plants; right tray, the treated inoculated and naturally infected inoculated plants.

B. A series of treated inoculated plants from the soil temperature experiments. Note the weakness of the stalks at temperatures of 28 and 30 degrees C., shown by leaning.

PRINCIPLES OF PLANT TAXONOMY, IV.*

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If the subkingdoms are properly delimited and if one has a knowledge of the general characters and the life histories of plants and if it is evident that a class should be the largest definitely determinable, monophyletic group in a subkingdom, then it becomes possible to establish such groups on a rather substantial foundation. In dividing plants into classes some attention should be given to the practical side of the problem. Each class should stand for some prominent segregative character or group of characters. At present 50 classes are recognized, several of which have only fossil members.

There is some difficulty in finding appropriate names for all the classes. All class names should be descriptive terms ending in *æ*, as Ascomycetæ, Hepaticæ, Coniferæ, Dicotylæ. At present such terms are not available for many of the class groups, and the writer, although originally equipped with a classical education, has up to the present time not found it agreeable to manufacture such names by the wholesale. Generic derivatives and older group names with the ending *eæ* have, therefore, been continued. All terms which necessarily have their endings in *i* or *es* have been discarded, for, as Saccardo pointed out, Ascomycetæ means "Plantæ Ascomycetæ" and it is improper to write the term Ascomycetes unless one is intending to use the English form. But the ending *eæ* is properly a tribe ending and must finally be discarded in class names.

Below, the classes of each subkingdom are segregated and defined, each one being followed by its proper number as it will stand in the phyletic system.

I. PROTOPHYTA. 3000 species. Plants giving no definite indication of a sexual nature.

SCHIZOMYCETÆ (1). Bacteria. 1350 species.

Simple unicellular or filamentous, fission fungi, parasitic, saprophytic or holophytic; non-motile or commonly with flagella or cilia,

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sometimes moving by means of cell contraction; nuclei primitive; often producing non-motile spores which can endure great extremes of heat and cold; cell division in one, two, or three directions; cells not naked nor amoeboid.

Myxoschizomycetæ (2). Slime-bacteria. 24 species.

Unicellular fission fungi with a slight, undulatory motion produced by the contraction of the cell, imbedded in a pesudo-plasmodium and moving about in a mass; forming peculiar sporangium-like bodies when passing into the resting or spore stage; cells not amoeboid. Saprophytes on decaying organic matter, like wood, straw, and manure.

Cyanophyceæ (3). Blue-green Algæ. 1,000 species.

Nonsexual algæ with phycocyanin, blue-green or brownish in color; unicellular, in colonies, plates, or masses, or in simple or branched, undifferentiated or differentiated filaments; cells with simple nuclei and primitive chromatophores; reproduction by simple fission or by hormogones, sometimes with special resting cells; cell wall usually gelatinous. Typically fresh-water plants, frequently occurring in hot springs, some growing in aerial conditions on soil, rocks and trees.

Glaucocysteæ (4). Higher Blue-green Algæ. 20 species.

Blue-green algæ with highly differentiated chromatophores and nuclei with nuclear membrane; unicellular or in colonies, the cells dividing in one direction. In water, on submerged Sphagnum, in salt marshes, and on wet limestone.

Autosporæ (9). Primitive Green Algæ. 200 species.

Simple, nonsexual, green algæ, unicellular, colonial, or filamentous, with reproduction by simple division or usually by autospores; cells normally with one nucleus, the nucleus with nuclear membrane. Mostly fresh-water or aerial plants.

Archemycetæ (10). Primitive Fungi. 200 species.

Simple, parasitic, often aquatic fungi without or with a very imperfect filamentous development; nonsexual, with zoospores or with thick-walled resting spores; zoospores usually penetrating into and developing in a cell of the host plant. Commonly growing in pollen-grains in water or in algæ, and occasionally in the leaves, stems, or roots of higher plants.

II. NEMATOPHYTA. 80,000 species. Plants with sexuality, rarely showing a complete loss of this condition, with various types of life cycles, but not with a typical antithetic alternation of generations having a parasitic sporophyte.

Acrasieæ (5). Primitive Slime Molds. 10 species.

Saprophytic, unicellular plants without chlorophyll, with an imperfect plasmodium of aggregated cells, the cells not fused together into a continuous mass; zoospores absent, spore masses without a covering wall. Plants showing some resemblance to the Rhizopoda and usually growing on the excrement of animals.

Myxomycetæ (6). Slime Molds. 350 species.

Unicellular, saprophytic, terrestrial fungi with primitive sexuality, occurring in plasmodial masses of more or less completely fused amoeboid cells which finally, with few exceptions, build up complex sporangium-like bodies or fructifications containing the spores; apparently with a simple haploid sexual cycle, the conjugation of nuclei taking place in the plasmodium at the time of the formation of the sporangium, the reduction division at the time of the formation of the resting spores; resting spores on germination giving rise to flagellate or amoeboid cells. Commonly on decaying wood and other dead organic matter.

Chlorococceæ (11). 250 species.

Simple, unicellular or colonial, sexual algæ with free zoospores or with ciliated cells united into colonies, usually green in color, but sometimes with other pigments; usually with normal cells containing one nucleus, rarely somewhat cenocytic, the colonial forms not produced by symmetrical aggregation of free zoospores. Reproduction by division, by zoospores and by free-swimming gametes, or by motile spermatozoids and staionary oospheres.

Hydrodictyeæ (12). 30 species.

Green cenocytic algæ growing in fresh water, consisting of colonies of peculiar form, often very symmetrical; sexual reproduction by the conjugation of equal motile gametes; nonsexual reproduction by zoospores which form the new colonies by symmetrical aggregation within the walls of the parent cenocyte or which are discharged together, enclosed in a delicate membrane.

Diatomeæ (7). Diatoms. 5,700 species.

Single-celled or somewhat filamentous algæ, usually of a brownish color, in which the cell wall becomes silicified and consists of two valves usually with fantastic markings or projections; reproduction by division or by the conjugation of two cells; the nonsexual forms probably degenerate. Marine and fresh-water plants of great abundance.

Conjugatæ (8). 2,300 species.

Unicellular or filamentous, normally unbranched and unattached, mostly fresh-water, green algæ with a single nucleus and with one or more highly specialized chloroplasts with pyrenoids in the cells; reproduction by division and by zygospores formed by the conjugation of two similar or nearly similar cells, often joined by the development of a special conjugation tube; aplanospores and parthenospores also frequently present.

Siphonocladeæ (13). Lower Tube Algæ. 450 species.

Cenocytic, filamentous, mostly septate and attached, green algæ with chloroplasts forming a net or rarely in separate plates; usually branched, isogamous or heterogamous, fresh-water or marine plants.

Siphoneæ (14). Higher Tube Algæ. 200 species.

Cenocytic, terrestrial, fresh-water, or marine, green algæ, usually filamentous, simple or branched, usually attached, and usually without

transverse septa in the vegetative parts; reproduction by zoospores, by ciliated gametes, or by true sperms and eggs; chloroplasts distinct, oval, lenticular, or plate-like.

Monoblepharideæ (15). 6 species.

Small, cenocytic fungi with transverse septa, with uniciliated zoospores and with a typical sexual reproduction; saprophytic and aquatic; eggs stationary in the oogonia, which open to admit the free-swimming uniciliated spermatozoids.

Confervеæ (16). Confervas. 650 species.

Simple or branched, filamentous, green algæ having normal cells with one nucleus; sometimes with the cells in disks or sheets; usually attached; reproduction by means of zoospores and by motile iso-gametes or by hetero-gametes, the eggs being stationary; chloroplasts one or more, usually with pyrenoids; mostly growing in fresh water.

Phaeospræ (17). Little Kelps. 550 species.

Normally brown-colored, marine algæ ranging from quite simple, filamentous forms to rather large organisms, usually attached; reproduction by zoospores produced in unilocular sporangia and by motile gametes produced in plurilocular gametangia; both types of sporangia exposed.

Cyclospræ (18). Rockweeds. 350 species.

Medium-sized to large, marine, brown algæ; attached, branched, and usually flat or flattish; reproduction by small biciliated sperms and large nonciliated eggs which are discharged and fertilized in the water; reproductive organs sunken in conceptacles; zoospores absent; with a simple diploid sexual cycle.

Laminarieæ (19). Giant Kelps. 100 species.

Large and highly developed, marine, brown algæ, with a distinct conducting tissue whose cells contain sieve-plates; frond usually prominently differentiated into holdfast, stalk, and leathery leaf-like structures; with an alternation of generations, the nonsexual spores (zoospores) produced in unilocular sporangia and giving rise to minute, filamentous, haploid, male and female gametophytes; sporophytes probably diploid; gametangia unilocular.

Dictyoteæ (20). 130 species.

Erect, attached, marine, brown algæ with flat leaf-like fronds and with an alternation of generations; nonsexual reproduction by non-motile tetraspores; sexual reproduction by means of non-ciliated eggs, produced singly and finally discharged from the ogonium, and sperms with one flagellum, produced in many-celled antheridia.

Monosporæ (21). 50 species.

Marine or fresh-water, red or purple algæ with filamentous or thalloid fronds; reproduction by single thallus cells and by the production of antheridia and oogonia from ordinary thallus cells, the antheridium developing nonciliated sperms, the oogonium, which is without a distinct trichogyne, usually developing a single, stationary egg.

FLORIDEÆ (22). 3,000 species.

Mostly marine, red or purple algæ, often of considerable size, filamentous or thalloid; reproduction by means of non-ciliated sperms produced in antheridia consisting of definite groups of cells, and eggs produced singly in the base of an oogonium which is prolonged above into a slender trichogyne. Plants with a definite alternation of generations, the fertilized egg having a complicated development, but in the simpler cases giving rise to a juvenile sporophytic body from which one to many carpospores are produced which on germination develop into a second sporophytic stage on which tetraspores are produced, following a reduction division, from which the gametophyte is again propagated.

CHAREÆ (23). Stoneworts. 160 species.

Green, erect, filamentous, mostly fresh-water algæ attached at the base by rhizoids; stems distinctly segmented into nodes and internodes, the nodes being marked by whorls of branches; plants usually with an incrustation of lime and the cells of the stem and branches often covered with a cortical layer of smaller cells; with a simple diploid sexual cycle; oogonia rounded, covered by a cortical layer of spiral branches; antheridia compound and very complex, composed of united branches to form a hollow, globular structure containing sperm-bearing filaments; spermatozoids spirally coiled, biciliated; nonsexual spores absent.

ZYGOMYCETÆ (24). 180 species.

Saprophytic or parasitic fungi with a nonseptate or nearly nonseptate mycelium having a conjugation of equal or nearly equal branches, one of which does not penetrate the other to any extent, the result of the conjugation being a simple or cenocytic zygospore; sometimes parthenogenetic; nonsexual spores nonmotile.

OOMYCETÆ (25). 185 species.

Mostly parasitic fungi with a nonseptate or nearly nonseptate mycelium, with conjugating branches, the one being much larger than the other which penetrates into its interior, or empties its contents into the larger, the result being a simple or cenocytic sexual spore; sometimes parthenogenetic; nonsexual, motile spores also produced which frequently develop in conidia.

ASCOMYCETÆ (26). Sack Fungi. About 18,000 typical species, besides 1,500 Lichens and 13,000 Deuteromycetæ.

Parasitic, helotic, or saprophytic fungi with a septate mycelium, the cells being uninucleate; and with asci usually containing a definite number, often eight, of ascospores, the asci produced as the result of a conjugation of two branches or cells of the mycelium, or apparently commonly through a more complicated sexual process with a binucleate-cell phase or conjugate generation prominently developed and ending in a true diploid nucleus which represents the zygote. The diploid nucleus on dividing undergoes reduction and by subsequent divisions the ascospores are formed; conidiospores commonly developed, in many groups the conidial stage only being known.

Laboulbenieæ (27). Beetle Fungi. 500 species.

Minute fungi with a septate body parasitic upon insects, usually beetles, connected with the host by means of a dark-colored, horny base serving as an organ of absorption and a holdfast; oogonium with a slender projection, the trichogyne, to which the nonmotile spermatia became attached and finally fertilize the oosphere below; as the result of fertilization a number of sacs or asci are produced which contain the ascospores.

Teliosporæ (28). Brand Fungi. 4,000 species.

Parasitic fungi with the septate mycelium developed in the tissues of the host, finally producing teliospores which on germinating give rise to septate or nonseptate basidia on which basidiospores are developed; some groups producing five kinds of spores; often heterecious; conjugate phase or generation with binucleate cells prominently developed and often reproducing itself by binucleate spores. Plants especially abundant on species of the grass family.

Basidiomycetæ (29). Basidium Fungi. 14,000 species.

Mostly large, saprophytic, sometimes parasitic fungi with a septate mycelium; developing septate or nonseptate basidia on the fruiting body or on the vegetative mycelium, not on special teliospores; basidia usually with four spores; conjugate phase prominent and the binucleate cells on dividing developing clamp-connections.

III. BRYOPHYTA. 17,000 species. Nonvascular plants with a continuously dependent sporophyte.

Hepaticæ (30). Liverworts. 4,000 species.

Gametophyte thalloid or a stem-like frond with scales which are without a costa, mostly dorsiventral, usually with a sack-like envelope, the perigynium, around the archegonia; rhizoids threadlike and unicellular; protonema usually small or only slightly developed, transient. Sporophyte either a spherical sporangium without foot or stalk, or differentiated into a sporangium, foot and elastically elongating stalk; sporangium without columella, usually with elaters, indehiscent, irregularly dehiscent at the top, or splitting into four valves from the summit, rarely developing an operculum.

Sphagneæ (31). Bog-mosses. 380 species.

Gametophyte a stem-like, erect, light, gray-green frond without a true central strand, but with large cortical cells, bearing numerous scales without a costa but with two kinds of cells, narrow ones with chlorophyll and large ones without, but commonly with holes in the walls and with spiral fibrils; rhizoids septate; protonema finally thalloid and flat; fruiting plant developing one or more pseudopodia which support the stemless sporophytes. Sporophyte with an expanded foot; sporangium with a shallow, dome-shaped spore-cavity in the upper part and with an operculum but without a peristome, elaters, or air cavities. Growing in bogs and wet places.

SCHIZOCARPÆ (32). Granite-mosses. 105 species.

Gametophyte a stem-like, erect frond without a central strand, bearing numerous scales without or with a costa; rhizoids consisting of cylindrical masses or plates of cells; protonema more or less thalloid. Sporophyte without a seta, but with a foot and finally carried upon a pseudopodium; sporangium without air cavities, splitting into four or more valves which are at first united at the top; spore-cavity cylindrical dome-shaped with an upward projecting central columella; elaters none; calyptra present on the sporophyte. Caespitose plants of a dark brown color growing on rocks.

ODONTOCARPÆ (Musci) (33). Mosses. 12,500 species.

Gametophyte a stem-like, erect or prostrate frond, usually with a well-developed central strand and usually with costate scales; rhizoids filamentous, septate; protonema usually well-developed and filamentous, sometimes persistent; psedopodium none. Sporophyte well-developed, with sporangium, foot, and usually with a well-developed hypophysis, and a seta with a central strand; sporangium usually with an operculum and a central columella extending entirely through the spore cavity, usually with a well-developed peristome and air spaces often communicating on the outside with true stomata; venter of the archegonium enlarging and usually ruptured at the base, the upper part being carried on top of the sporangium as the calyptra.

ANTHOCEROTÆ (34). Hornworts. 105 species.

Gametophyte a dorsiventral, thalloid frond without scales or with imperfectly developed scales but with unicellular rhizoids; sexual organs imbedded in the tissue of the thallus; protonema small and transient. Sporophyte with a slender horn-like or pod-like sporangium and with a bulbous foot containing an irregular surface with wart-like projections; sporangium with a central columella, two-valved, with small irregular elaters among the spores; epidermis with or without stomata; cells mostly with a single large chloroplast; intercalary growth present between the foot and sporangium.

IV. PTERIDOPHYTA HOMOSPORÆ. 7000 species. Homosporous vascular plants in which the sex is determined in a haploid cell of the gametophyte.

PHYLLOPTERIDÆ (Filices) (35). Ferns. 6500 species.

Sporophyte herbaceous or tree-like, indeterminate in growth, usually with a horizontal, simple or branched rhizome; leaves usually large, spirally arranged, and mostly compound, rarely narrow and grass-like; sporangia borne on the underside of the leaf, or on the morphologically upper side on simple or branched sporangiophores; eusporangiate or leptosporangiate, with or without indusia; sporophylls never in cones. Gametophyte comparatively large, tuber-like, without chlorophyll and subterranean, or usually developed as a flat, simple or rarely branched thallus, usually hermaphroditic but unisexual in some of the higher forms; spermatozoids multiciliate.

Sphenophylleæ (38). Fossil.

Paleozoic plants of moderate dimensions with solid, jointed stems with a central, triarch vascular bundle; leaves mostly wedge-shaped, comparatively small; sporophylls in cones.

Equiseteæ (39). Horsetails. 25 species.

Sporophyte perennial, herbaceous, with a rhizome and with jointed, mostly hollow, simple or branched, annual or perennial, aerial stems; vascular bundles in a circle; leaves reduced to sheaths around the joints, the sheaths toothed; cones terminal with small peltate sporophylls arranged in whorls; sporangia sack-like, eusporangiate; lowest whorl of the cone of united segments developing sporangia on the upper side in the lower species but forming a sterile calyx in the highest; spores with 4 narrow, strap-like, spiral, hygroscopic appendages formed from the outer wall. Gametophyte a small green thallus hermaphroditic or unisexual with frequent sex-reversal; spermatozoids multiciliate.

Lycopodieæ (41). Lycopods. 160 species.

Sporophyte perennial, herbaceous, with or without a rhizome the aerial stems upright or trailing; branching dichotomous; leaves small, without a ligule, spirally arranged on the stem, two-to many-ranked; sporangia solitary on the upper surface of the leaves or in their axils, sometimes trilocular, eusporangiate; sporophylls in bands or zones alternating with the foliage leaves or arranged in terminal cones; spores small, not appendaged. Gametophyte small, sometimes subterranean, with or without chlorophyll, hermaphroditic; spermatozoids small, biciliate.

V. PTERIDOPHYTA HETEROSPORÆ. 800 species. Seedless plants with two kinds of nonsexual spores, the sex being determined in a diploid cell of the sporophyte.

Isoeteæ (36). Quillworts. 64 species.

Sporophyte with a short, tuberous stem with a peculiar type of secondary thickening and with long, erect, grass-like leaves which have a ligule; roots dichotomous; microsporangia and megasporangia large, borne singly, sunken in the upper side of the expanded bases of the leaves, eusporangiate. Gametophytes very much reduced, unisexual; spermatozoids large, spirally coiled, multiciliate.

Hydropteridæ (37). Water-ferns. 75 species.

Sporophytes small with a horizontal rhizome or floating on the surface of the water; leaves alternate or whorled; internodes mostly well-developed; microsporangia and megasporangia borne together on the same leaf, enclosed in true sporocarps or apparent sporocarps, leptosporangiate. Gametophytes developing entirely within the spore walls or protruding only slightly, very short-lived; spermatozoids large spirally coiled, multiciliate.

CALAMARIÆ (40). Calamites. Fossil.

Paleozoic plants, sometimes of tree-like aspect and dimensions, with hollow, jointed stems and with a circle of colateral bundles; stems increasing in diameter by a cambium zone; heterosporous, the sporophylls in cones.

SELAGINELLEÆ (42). Selaginellas. 600 living species.

Small herbs or many of the fossil forms large trees. Sporophytes of living species erect, or ascending, or sometimes creeping and dorsiventral, with dichotomous stems and dichotomous roots; leaves small spirally arranged or sometimes opposite, ligulate; cells often with a single chloroplast; sporophylls in bisporangiate cones, the eusporangiate microsporangia and megasporangia single on the base of the upper side of the sporophylls. Gametophytes minute and short-lived; spermatozoids minute, biciliate. Some fossil species developed into large trees with secondary thickening by a cortical meristem and with a dichotomous branching system developed at the base as well as at the top of the stem, apparently being the first sporophytes with a successful basal growth.

VI. GYMNOSPERMÆ. 500 living species. Seed plants with open carpels.

PTERIDOSPERMÆ (43). Fossil.

Paleozoic seed-plants of fern-like aspect; stems short and usually erect, increasing in thickness and bearing mostly compound leaves.

CYCADEÆ (44). Cycads. 95 living species.

Sporophyte with erect, often woody, simple or little-branched stems or occasionally geophilous, bearing compound leaves; vascular bundles collateral, increasing in thickness by their cambiums; cortical meristems developed in some species in which new circles of bundles are produced; sporophylls in cones or the carpels sometimes merely in zones through which the stem grows; living species diecious; ovules with pollen-chambers; embryo with 2 cotyledons, rarely one. Female gametophyte becoming large and fleshy; male gametophyte, or pollengrain developing two or more large, spirally coiled and multiciliate spermatozoids.

CORDAITEÆ (45). Fossil.

Paleozoic, sparsely branched trees bearing large, long, parallel-veined leaves spirally arranged.

GINKGOÆ (46). Maiden-hair-trees. 1 living species.

Sporophytes developing into large trees with a cambium layer from which annual rings of wood are produced, with a crown of numerous branches of two types, long branches with internodes and dwarf branches without, with spirally arranged, broad, dichotomously veined, deciduous leaves, and without flowers but with zones of sporophylls on some of the dwarf branches; ovule with pollen-chamber; cotyledons 2, the embryo sometimes not developing until the seed drops to the ground. Female gametophyte becoming large in the seed which has a bony inner and a fleshy outer coat; male gametophyte developing 2 large, spirally coiled, multiciliate spermatozoids.

Coniferæ (47). Conifers. 350 species.

Sporophytes developing as large trees or shrubs, much branched, with or without dwarf branches; stems with a normal cambium, no vessels in the secondary wood, resin commonly present; leaves mostly small, scale-like, linear, or needle-like, rarely broad; flowers monosporangiate, monecious or diecious, the higher types much reduced; cotyledons 2-15; ovule without pollen-chamber. Female gametophyte usually comparatively small; pollengrains sometimes winged, producing two non-motile sperms.

Gneteæ (48). 50 species.

Sporophytes developing as shrubs or lianas, or rarely as trees, with branched or rarely simple stems; secondary wood containing vessels representing enlarged tracheids; leaves simple, opposite or whorled, sometimes reduced to dry bracts but often large; flowers monecious or mainly diecious, collected in specialized inflorescences; resin passages none; cotyledons two. Gametophytes small, various in character, the sperms not motile.

VII. ANGIOSPERMÆ. 150,000 species. Seed plants with closed carpels and with stigmas; xeniophyte usually present.

Monocotylæ (49). Monocotyls. 25,000 species.

Sporophytes developing as herbs or sometimes as woody plants of large dimensions; embryo usually with one terminal cotyledon and usually with a lateral plumule; stem with closed, usually scattered vascular bundles, without typical bark and without annual rings of growth, rarely with secondary thickening; leaves mostly parallel-veined, sometimes netted-veined; flowers mostly of the trimerous and typically of the pentacyclic type.

Dicotylæ (50). Dicotyls. 125,000 species.

Sporophytes developing as herbs or woody plants; embryo with two cotyledons, rarely with more or with only one, and with a terminal plumule; stem with open vascular bundles, usually arranged in a circle and developing a continous cambium cylinder, forming annual rings of growth in the case of perennial stems, with bark on the outside; leaves usually netted veined; flowers more commonly pentamerous or tetramerons, the higher types usually tetracyclic.

Synopsis of the Plant Phyla and Sub-phyla.

It is possible, in a vague way, to see monophyletic relationships among certain classes. These apparently related classes can then be combined into convenient larger groups, the Phyla. The phyla represent the largest taxonomic groups.

In establishing phyla, regard should be had for convenience and practical usability as in the case of the classes. Most

systematists would probably agree that all the META-THALLOPHYTA are monophyletic as compared with the THALLOPHYTA. This is no reason, however, for establishing such a complex system as a single phylum in contrast to numerous phyla in the Thallophyta as is sometimes done. It is evident that from the evolutionary point of view, all the Thallophyta have also come from a common source and are in this sense monophyletic. The aim should be to segregate great branches or groups of somewhat similar value and importance. It seems to the writer that about 15 main groups will make a satisfactory system, although he has no quarrel with any one who thinks there should be several more, so long as the groups are practical and of more or less equal value.

I. Plant body unicellular, colonial, or multicellular, frequently filamentous; ovary when present never an archegonium; nonsexual plants or with a simple haploid or a simple diploid sexual cycle, sometimes with haploid and conjugate phases, the conjugate phase with binucleate cells, sometimes with an alternation of haploid and diploid generations, but then not of the typical antithetic type, the diploid sporophyte never having a parasitic existence or proper parasitic phase on the parent gametophyte, but originating from a free spore or zygote.....(THALLOPHYTA).

A. Cells typically with poorly differentiated nuclei and chromatophores and with a primitive type of nuclear division; motile or nonmotile, with or without chlorophyll, never with a pure chlorophyll-green color; reproduction by fission; resting spores or cells commonly present.....Phylum I. SCHIZOPHYTA. 1, 2, 3, 4.

B. Cells with well differentiated nuclei and if holophytic usually with definite chloroplasts; with or without chlorophyll; plants green or colorless or variously tinted by coloring matter other than chlorophyll.

(A). Unicellular saprophytic plants without chlorophyll, having a plasmodium stage of more or less completely fused cells, mostly amoeboid in nature, from which complex sporangium-like resting bodies are built up; sexuality primitive, consisting of the conjugation of nuclei in the plasmodium at the time the sporangia develop; resting spores finally liberating flagellate or amoeboid cells.....Phylum II. MYXOPHYTA. 5, 6.

(B). Plants not developing a plasmodium, the cells usually covered with a wall during the vegetative phase.

1. Unicellular or filamentous plants containing chlorophyll, either brown and with silicious, two-valved walls or green with complex chromatophores and the walls not silicified; conjugating cells not ciliated, isogamous; with a simple haploid sexual cycle, the reduction division probably always in the zygote.....Phyllum III. ZYGOPHYTA.

a. With silicified cell walls and brown coloring matter. Subphylum and class 1.....DIATOMEÆ. 7.

b. Not with silicified walls; cells green. Subphylum and class 2.....CONJUGATÆ. 8.

2. Plants not with silicified two-valved walls; either nonsexual or isogamous or heterogamous; if with a direct conjugation of walled cells or branches then without chlorophyll.
   (1). Plants with chlorophyll, or if without chlorophyll, then either without a true mycelium, or if a mycelium-like filament is present then with a sexual phase with ciliated, motile spermatozoids and stationary eggs.
      a. Antheridium when present not consisting of a globular structure containing sperm-bearing filaments.
         (a). Plants usually green, with chlorophyll or colorless, nearly all producing nonsexual zoospores; unicellular, colonial, or multicellular, nonsexual or mostly sexual plants, the sexual forms isogamous or heterogamous; nearly all with simple, haploid, sexual cycle, but some apparently with a simple, diploid, sexual cycle.
            Phylum IV. GONIDIOPHYTA. 9, 10, 11, 12, 13, 14, 15, 16.
         (b). Plants with the chlorophyll usually hidden by a brown, red, or purple pigment, always with a multicellular body and sexuality.
            ((a)). Mostly marine brown algæ with phycophaein; isogamous or heterogamous with ciliated sperms, both gametes usually discharged from the gametangia; with a simple, diploid, sexual cycle, perhaps some also with a simple, haploid sexual cycle, or in the higher forms with two or more types of the alternation of generations cycle.
               Phylum V. PHAEOPHYTA. 17, 18, 19, 20.
            ((b)). Mostly marine red or purple algæ with phyco-erythrin; heterogamous, with stationary eggs and nonciliated sperms; apparently normally with an alternation of generations.
               Phylum VI. RHODOPHYTA. 21, 22.
      b. Filamentous, aquatic, green algæ with globular antheridia containing sperm-bearing filaments, the sperms being biciliated; nonsexual spores absent; with a simple, diploid, sexual cycle, the reduction division apparently taking place in the sexual organs.
         Phylum VII. CHAROPHYTA. 23.
   (2). Plants without chlorophyll and with a true septate or nonseptate mycelium; sexual reproduction without motile sperms; nonsexual reproduction of various types; with a simple, haploid, sexual life cycle, or in the higher forms with a modification of this cycle, in which a binucleate or conjugate phase follows the normal haploid phase with uninucleate cells.....Phylum VIII. MYCOPHYTA.
      a. Mycelium cenocytic; without ascospores or basidiospores.....Subphylum I. PHYCOMYCETÆ. 24, 25.
      b. Mycelium normally not cenocytic, with ascospores or basidiospores, or apparently numerous degenerate forms in which such spores are no longer developed, but which are propagated solely by conidia.
         Subphylum 2. MYCOMYCETÆ. 26, 27, 28, 29.

II. Plant body a solid aggregate; if filamentous, only so in the embryonic or immature condition; ovary a typical archegonium or if much reduced then the plants seed-bearing; always with a typical, antithetic alternation of generations in the normal life cycle, the diploid sporophyte being parasitic during its entire life or in its embryonic phase on the sporophyte.
   (META-THALLOPHYTA).

A. Without vascular tissue; sporophyte parasitic on the gametophyte during its entire life and determinate in growth; homosporous; small plants without roots or true leaves.
Phylum IX. Bryophyta. 30, 31, 32, 33, 34.

B. Always with vascular tissue in the sporophyte which becomes an independent plant, after the embryonic phase, with roots and leaves except in a few degenerate forms; and always with decidedly indeterminate growth of all or part of the axes.

(A). Sporophyte not seed-producing; sperms breaking out of the antheridium to enter the necks of the archegonia directly; homosporous or heterosporous, the sex being determined either in the gametophyte or in the sporophyte.

1. Spermatozoids comparative large and multiciliate; sporophylls not in cones, or in cones (strobili or primitive flowers), but then the sporophyte with jointed stems and whorled leaves; branching normally monopodial.
   a. Stems not jointed, the leaves usually large and compound and spirally arranged, rarely in whorles; sporophylls never in cones, the reproductive axes always indeterminate.....Phylum X. Ptenophyta. 35, 36, 37.
   b. Stems jointed and fluted, bearing whorled leaves, which in living forms and in most fossil forms are much reduced; sporophylls in cones; living species, and many fossil forms also, with some determinate vegetative branches.
   Phylum XI. Calamophyta. 38, 39, 40.

2. Spermatozoids small, biciliate; leaves of the living species small, covering the continuous stem in spirals, or sometimes in opposite arrangement; rarely with a slight internodal development; branching of the stem dichotomous, the lowest species all indeterminate; sporophylls usually in cones or in the lower forms in zones alternating with the sterile leaves; frequently also with determinate vegetative branches.
Phylum XII. Lepidophyta. 41, 42.

(B). Sporophyte producing seeds, the female gametophyte always parasitic in the megasporangium (ovule) during its entire life, the male gametophyte developing a pollen-tube through which the sperms are discharged, hence with a two-phased parasitic growth, the first stage in the microsporangium, the second in the ovule, or in the higher groups beginning in the tissues of the megasporophyll itself (carpel); with a resting stage intercalated between the two phases of the sporophyte; always heterosporous; the sex being determined in the sporophyte.

1. Carpels open, without stigmas or true ovularies, the ovules and seeds naked and the pollen-grains (male gametophytes) falling directly into the micropyle; no true endosperm or xeniophyte present.
   a. Sperms so far as known ciliated and motile; ovules with a pollen-chamber; with or without flowers, the sporophylls either being in cones, or in rosettes on indeterminate axes.
   Phylum XIII. Cycadophyta. 43, 44, 45, 46.
   b. Sperms without cilia; ovules without pollen-chambers; sporophylls in cones, which may be highly specialized or reduced and in the highest types collected into definite inflorescences; woody plants, monecious or diecious.
   Phylum XIV. Strobilophyta. 47, 48.

2. Carpels or the set of carpels closed at maturity, with stigmas and with ovularies enclosing the ovules and seeds; pollen-grains falling on the stigma and developing long pollen-tubes; flowers well developed, commonly with a perianth, often highly specialized or reduced; true endosperm or xeniophyte normally present.....Phylum XV. Anthophyta. 49, 50.

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